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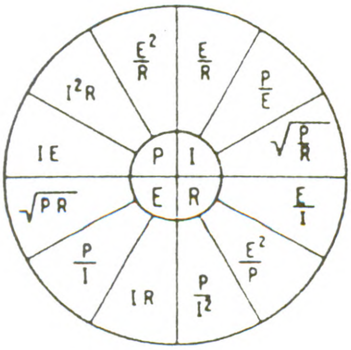
Training Manual
(TRAMAN)

Navy Electricity and Electronics Training Series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Module 1—Introduction to Matter, Energy, and Direct Current

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Although the words "he," "him," and "his" are used sparingly in this manual to enhance communication, they are not intended to be gender driven nor to affront or discriminate against anyone reading this text.

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PREFACE

Introduction to Matter, Energy, and Direct Current and its associated nonresident training course form a self-study package which is part of the *Navy Electricity and Electronics Training Series (NEETS).* This module is written for the men and women of the U. S. Navy and Naval Reserve whose duties require them to have a knowledge of the fundamentals of electricity. It begins with a brief history of the growth and development of the modern technological age within the Navy. The need for a background in electricity and electronics for nearly everyone concerned with the operation and maintenance of modern Navy equipment is also explained. The study begins with an introduction to matter—its makeup and its behavior. The student will become familiar with the building blocks of nature (molecules, atoms, electrons, etc.), and the processes by which particles become electrified. This study will include magnetism and its effects on electricity, common means of producing electricity, discussions of how electrity works, and what affects the behavior of electricity. Each topic will conclude with a summary. The module closes with electrical safety precautions and first aid.

This training manual and the nonresident training course (NRTC) were prepared by the Naval Education and Training Program Management Support Activity, Pensacola, Florida, for the Chief of Naval Education and Training.

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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NAVY ELECTRICITY AND ELECTRONICS TRAINING SERIES

The Navy Electricity and Electronics Training Series (NEETS) was developed for use by personnel in many electrical and electronic related Navy ratings. Written by, and with the advice of, senior technicians in these ratings, this series provides beginners with fundamental electrical and electronic concepts through the medium of self-study. The presentation is not oriented to any specific rating structure.

The series is divided into modules that contain related information organized in traditional paths of instruction. The first module in the series introduces you to the course with a short history of electricity and electronics, and proceeds into the characteristics of matter, energy, and direct current. Module 1 also describes some of the general safety precautions and first-aid procedures that should be common knowledge for a person working in the field of electricity. Related safety hints are located throughout the rest of the series. Module 2 is an introduction to alternating current and transformers. It discusses basic ac theory and the fundamentals of electromagnetism, inductance, capacitance, impedance, and transformers. Module 3 deals with circuit breakers, fuses, and current limiters used in circuit protection. This module also discusses the theory and use of meters as electrical measuring devices. Module 4 presents the use of conductors, the insulation used as wire covering, splicing, termination of wiring, soldering techniques, and reading electrical wiring diagrams. Module 5 is an introduction to generators and motors. It covers the uses of ac and dc generators and motors in the conversion of electrical and mechanical energy. Module 6 ties the first five modules together in an introduction to vacuum tubes and the vacuum-tube power supply. Module 7 does the same thing, using solid-state devices. The series continues into amplifiers (module 8) and wave-generation and wave-shaping circuits (module 9). Module 10 discusses the characteristics of wave propagation, transmission lines and antennas. Module 11, entitled *Microwave Principles*, explains microwave oscillators, amplifiers, and waveguides. The principles of modulation are discussed in module 12. Module 13 presents the fundamental concepts of number systems, Boolean algebra, and logic circuits, which pertain to digital computers. Module 14 is devoted to the technology of microelectronics and the repair of miniature and microminiature circuits. The basic principles, operations, functions, and applications of synchro, servo, and gyro mechanisms are covered in module 15. The module on test equipment, module 16, introduces the beginner to some of the more commonly used pieces of test equipment and their applications. Module 17 presents the fundamentals of a radio-frequency communication system. Module 18 covers the fundamentals of a radar system. Module 19 is called *The Technician's Handbook*. Its purpose is to provide the technician with a handy reference of commonly used general information. It contains information, such as electrical and electronic formulas, color coding, and Navy supply system information. Module 20 is the master glossary of terms and index for the series. Module 21 introduces the technician to alternative methods of performing electronics measurements. Module 22 is an introduction to digital computers. Module 23 is an introduction to the use and maintenance of magnetic recorders and the concepts of recording on magnetic tape and disks.

An individual just becoming acquainted with electricity or electronics should study the modules in their suggested sequence. The series is designed to give a student small amounts of information that can be easily digested before advancing further into the more complex material.

Comprehension check questions are distributed throughout each of the modules, except for modules 19 and 20, which are used as references. If you have difficulty in answering the questions, you should restudy the applicable paragraph(s). Answers to the questions are given on the next even-numbered page.

Although an attempt has been made to use simple language, various technical words and phrases have necessarily been included. These are explained both in the text and in the glossary provided at the end of each module. Specific terms are also defined in module 20, the *Master Glossary and Index.*

Considerable emphasis has been placed on the use of illustrations to provide a maximum amount of information. In some instances, a knowledge of basic algebra may be required.

A nonresident training course (NRTC) is provided for each module with the exceptions of *The Technician's Handbook* (module 19) and *The Master Glossary and Index* (module 20). Course descriptions and ordering information are found in NAVEDTRA 12061, *List of Training Manuals and Correspondence Courses.*

NAVY ELECTRICITY AND ELECTRONICS TRAINING SERIES

Module 1	Introduction to Matter, Energy, and Direct Current
Module 2	Introduction to Alternating Current and Transformers
Module 3	Introduction to Circuit Protection, Control, and Measurement
Module 4	Introduction to Electrical Conductors, Wiring Techniques, and Schematic Reading
Module 5	Introduction to Generators and Motors
Module 6	Introduction to Electronic Emission, Tubes, and Power Supplies
Module 7	Introduction to Solid-State Devices and Power Supplies
Module 8	Introduction to Amplifiers
Module 9	Introduction to Wave-Generation and Wave-Shaping Circuits
Module 10	Introduction to Wave Propagation, Transmission Lines, and Antennas
Module 11	Microwave Principles
Module 12	Modulation Principles
Module 13	Introduction to Number Systems and Logic Circuits
Module 14	Introduction to Microelectronics
Module 15	Principles of Synchros, Servos, and Gyros
Module 16	Introduction to Test Equipment
Module 17	Radio-Frequency Communications Principles
Module 18	Radar Principles
Module 19	The Technician's Handbook
Module 20	Master Glossary and Index
Module 21	Test Methods and Practices
Module 22	Introduction to Digital Computers
Module 23	Magnetic Recording

TOPIC 1

MATTER, ENERGY, AND ELECTRICITY

LEARNING OBJECTIVES

Learning objectives are stated at the beginning of each topic. These learning objectives serve as a preview of the information you are expected to learn in the topic. The comprehensive check questions are based on the objectives. By successfully completing the NRTC, you indicate that you have met the objectives and have learned the information. The learning objectives are listed below.

Upon completing this topic, you will be able to:

1. State the meanings of and the relationship between matter, element, nucleus, compound, molecule, mixture, atom, electron, proton, neutron, energy, valence, valence shell, and ion.

2. State the meanings of and the relationship between kinetic energy, potential energy, photons, electron orbits, energy levels and shells and subshells.

3. State, in terms of valence, the differences between a conductor, an insulator, and a semiconductor, and list some materials which make the best conductors and insulators.

4. State the definition of static electricity and explain how static electricity is generated.

5. State the meanings of retentivity, reluctance, permeability, ferromagnetism, natural magnet, and artificial magnet as used to describe magnetic materials.

6. State the Weber and domain theories of magnetism and list six characteristics of magnetic lines of force (magnetic flux), including their relation to magnetic induction, shielding, shape, and storage.

7. State, using the water analogy, how a difference of potential (a voltage or an electromotive force) can exist. Convert volts to microvolts, to millivolts, and to kilovolts.

8. List six methods for producing a voltage (emf) and state the operating principles of and the uses for each method.

9. State the meanings of electron current, random drift, directed drift, and ampere, and indicate the direction that an electric current flows.

10. State the relationship of current to voltage and convert amperes to milliamperes and microamperes.

11. State the definitions of and the terms and symbols for resistance and conductance, and how the temperature, contents, length and cross-sectional area of a conductor affect its resistance and conductance values.

12. List the physical and operating characteristics of and the symbols, ratings, and uses for various types of resistors; use the color code to identify resistor values.

INTRODUCTION

The origin of the modern technical and electronic Navy stretches back to the beginning of naval history, when the first navies were no more than small fleets of wooden ships, using wind-filled sails and manned oars. The need for technicians then was restricted to a navigator and semiskilled seamen who could handle the sails.

As time passed, larger ships that carried more sail were built. These ships, encouraging exploration and commerce, helped to establish world trade routes. Soon strong navies were needed to guard these sea lanes. Countries established their own navies to protect their citizens, commercial ships, and shipping lanes against pirates and warring nations. With the addition of mounted armament, gunners joined the ship's company of skilled or semiskilled technicians.

The advent of the steam engine signaled the rise of an energy source more practical than either wind and sails or manpower. With this technological advancement, the need for competent operators and technicians increased.

However, the big call for operators and technicians in the U. S. Navy came in the early part of the 20th century, when power sources, means of communication, modes of detection, and armaments moved with amazing rapidity toward involved technical development. Electric motors and generators by then had become the most widely used sources of power. Telephone systems were well established on board ship, and radio was being used more and more to relay messages from ship to ship and from ship to shore. Listening devices were employed to detect submarines. Complex optical systems were used to aim large naval rifles. Mines and torpedoes became highly developed, effective weapons, and airplanes joined the Navy team.

During the years after World War I, the Navy became more electricity and electronic minded. It was recognized that a better system of communications was needed aboard each ship, and between the ships, planes, submarines, and shore installations; and that weaponry advances were needed to keep pace with worldwide developments in that field. This growing technology carried with it the awareness that an equally skilled force of technicians was needed for maintenance and service duties.

World War II proved that all of the expense of providing equipment for the fleet and of training personnel to handle that equipment paid great dividends. The U. S. Navy had the modern equipment and highly trained personnel needed to defeat the powerful fleets of the enemy.

Today there is scarcely anyone on board a Navy ship who does not use electrical or electronic equipment. This equipment is needed in systems of electric lighting and power, intercommunications, radio, radar, sonar, loran, remote metering, weapon aiming, and certain types of mines and torpedoes. The Navy needs trained operators and technicians in this challenging field of electronics and electricity. It is to achieve this end that this module, and others like it, are published.

MATTER, ENERGY, AND ELECTRICITY

If there are roots to western science, they no doubt lie under the rubble that was once ancient

Greece. With the exception of the Greeks, ancient people had little interest in the structure of materials. They accepted a solid as being just that—a continuous, uninterrupted substance. One Greek school of thought believed that if a piece of matter, such as copper, were subdivided, it could be done indefinitely and still only that material would be found. Others reasoned that there must be a limit to the number of subdivisions that could be made and have the material still retain its original characteristics. They held fast to the idea that there must be a basic particle upon which all substances are built. Recent experiments have revealed that there are, indeed, several basic particles, or building blocks within all substances.

The following paragraphs explain how substances are classified as elements and compounds, and are made up of molecules and atoms. This, then, will be a learning experience about protons, electrons, valence, energy levels, and the physics of electricity.

MATTER

Matter is defined as anything that occupies space and has weight; that is, the weight and dimensions of matter can be measured. Examples of matter are air, water, automobiles, clothing, and even our own bodies. Thus, we can say that matter may be found in any one of three states: SOLID, LIQUID, and GASEOUS.

ELEMENTS AND COMPOUNDS

An ELEMENT is a substance which cannot be reduced to a simpler substance by chemical means. Examples of elements with which you are in everyday contact are iron, gold, silver, copper, and oxygen. There are now over 100 known elements. All the different substances we know about are composed of one or more of these elements.

When two or more elements are chemically combined, the resulting substance is called a COMPOUND. A compound is a chemical combination of elements which can be separated by chemical but not by physical means. Examples of common compounds are water, which consists of hydrogen and oxygen, and table salt, which consists of sodium and chlorine. A MIXTURE, on the other hand, is a combination of elements and compounds, not chemically combined, that can be separated by physical means. Examples of mixtures are air, which is made up of nitrogen, oxygen, carbon dioxide, and small amounts of several rare gases, and sea water, which consists chiefly of salt and water.

Q1. What is matter, and in what three states is it found?

Q2. What is an element?

Q3. What is a compound?

Q4. What is the difference between a compound and a mixture?

MOLECULES

A MOLECULE is a chemical combination of two or more atoms, (atoms are described in the next paragraph). In a compound the molecule is the smallest particle that has all the characteristics of the compound.

Consider water, for example. Water is matter, since it occupies space and has weight. Depending on the temperature, it may exist as a liquid (water), a solid (ice), or a gas (steam). Regardless of the temperature, it will still have the same composition. If we start with a quantity of water, divide this and pour out one half, and continue this process a sufficient number of times, we will eventually end up with a quantity of water which cannot be further divided without ceasing to be water. This quantity is called a molecule of water. If this molecule of water is divided, instead of two

A1. **Anything that occupies space and has weight. Solids, liquids, gases**

A2. **A substance which cannot be reduced to a simpler substance by chemical means**

A3. **A substance consisting of two or more elements**

A4. **A compound is a chemical combination of elements that cannot be separated by physical means. A mixture is a physical combination of elements and compounds that are not chemically combined.**

---

parts of water, there will be one part of oxygen and two parts of hydrogen (H_2O).

ATOMS

Molecules are made up of smaller particles called ATOMS. An atom is the smallest particle of an element that retains the characteristics of that element. The atoms of one element, however, differ from the atoms of all other elements. Since there are over 100 known elements, there must be over 100 different atoms, or a different atom for each element. Just as thousands of words can be made by combining the proper letters of the alphabet, so thousands of different materials can be made by chemically combining the proper atoms.

Any particle that is a chemical combination of two or more atoms is called a molecule. The oxygen molecule consists of two atoms of oxygen, and the hydrogen molecule consists of two atoms of hydrogen. Sugar, on the other hand, is a compound composed of atoms of carbon, hydrogen, and oxygen. These atoms are combined into sugar molecules. Since the sugar molecules can be broken down by chemical means into smaller and simpler units, we cannot have sugar atoms.

The atoms of each element are made up of electrons, protons, and, in most cases, neutrons, which are collectively called subatomic particles. Furthermore, the electrons, protons, and neutrons of one element are identical to those of any other element. The reason that there are different kinds of elements is that the number and the arrangement of electrons and protons within the atom are different for the different elements.

The electron is considered to be a small negative charge of electricity. The proton has a positive charge of electricity equal and opposite to the charge of the electron. Scientists have measured the mass and size of the electron and proton, and they know how much charge each possesses. The electron and proton each have the same quantity of charge, although the mass of the proton is approximately 1837 times that of the electron. In some atoms there exists a neutral particle called a neutron. The neutron has a mass approximately equal to that of a proton, but it has no electrical charge. According to a popular theory, the electrons, protons, and neutrons of the atoms are thought to be arranged in a manner similar to a miniature solar system. The protons and neutrons form a heavy nucleus with a positive charge, around which the very light electrons revolve.

Figure 1-1 shows one hydrogen and one helium atom. Each has a relatively simple structure. The hydrogen atom has only one proton in the nucleus with one electron rotating about it. The helium atom is a little more complex. It has a nucleus made up of two protons and two neutrons, with two electrons rotating about the nucleus. Elements are classified numerically according to the complexity of their atoms. The atomic number of an atom is determined by the number of protons in its nucleus.

In a neutral state, an atom contains an equal number of protons and electrons. Therefore, an atom of hydrogen—which contains one proton and one electron—has an atomic number of 1; and helium, with two protons and two electrons, has an atomic number of 2. The complexity of atomic structure increases with the number of protons and electrons.

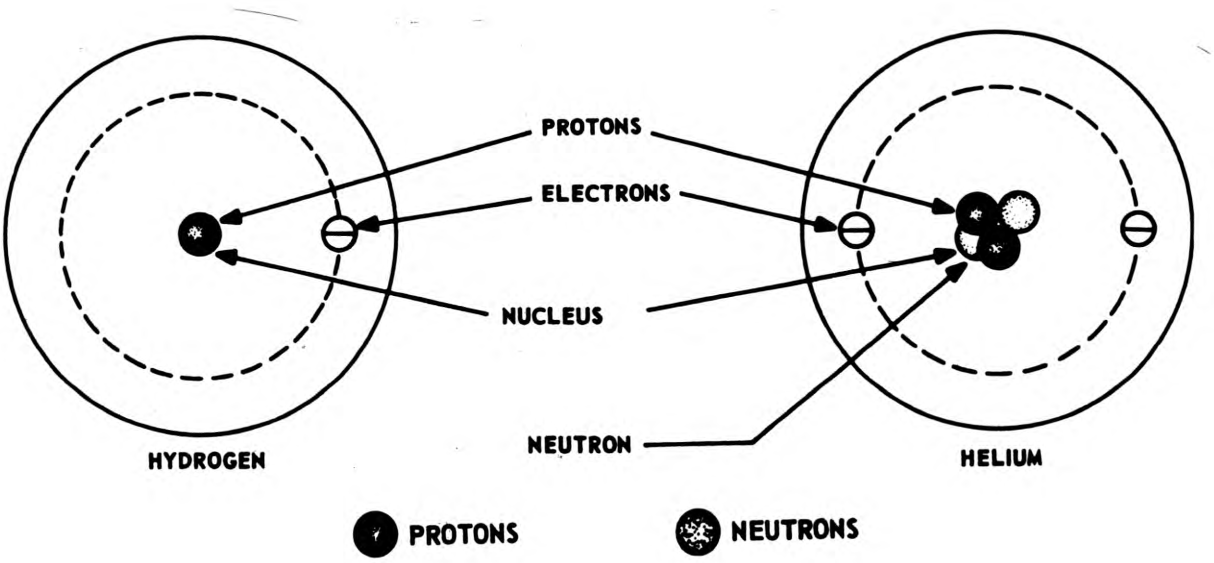

Figure 1-1.—Structures of simple atoms.

Q5. What is a molecule?

Q6. What are the three types of subatomic particles, and what are their charges?

Energy Levels

Since an electron in an atom has both mass and motion, it contains two types of energy. By virtue of its motion the electron contains KINETIC ENERGY. Due to its position it also contains POTENTIAL ENERGY. The total energy contained by an electron (kinetic plus potential) is the factor which determines the radius of the electron orbit. In order for an electron to remain in this orbit it must neither GAIN nor LOSE energy.

It is well known that light is a form of energy, but the physical form in which this energy exists is not known.

One accepted theory proposes the existence of light as tiny packets of energy called PHOTONS. Photons can contain various quantities of energy. The amount depends upon the color of the light involved. Should a photon of sufficient energy collide with an orbital electron, the electron will absorb the photon's energy, as shown in figure 1-2. The electron, which now has a greater than normal amount of energy, will jump to a new orbit farther from the nucleus. The first new orbit to which the electron can jump has a radius four times as large as the radius of the original orbit. Had the electron received a greater amount of energy, the next possible orbit to which it could jump would have a radius nine times the original. Thus, each orbit may be considered to represent one of a large number of energy levels that the electron may attain. It must be emphasized that the electron cannot jump to just any orbit. The electron will remain in its lowest orbit until a sufficient amount of energy is available, at which time the electron will accept the energy and jump to one of a series of permissible orbits. An electron cannot exist in the space between energy levels. This indicates that the electron will not accept a photon of energy unless it contains enough energy to elevate itself to one of the higher energy levels. Heat energy and collisions with other particles can also cause the electron to jump orbits.

A5. **A chemical combination of two or more atoms**

A6. **Electrons-negative, protons-positive, and neutrons-neutral**

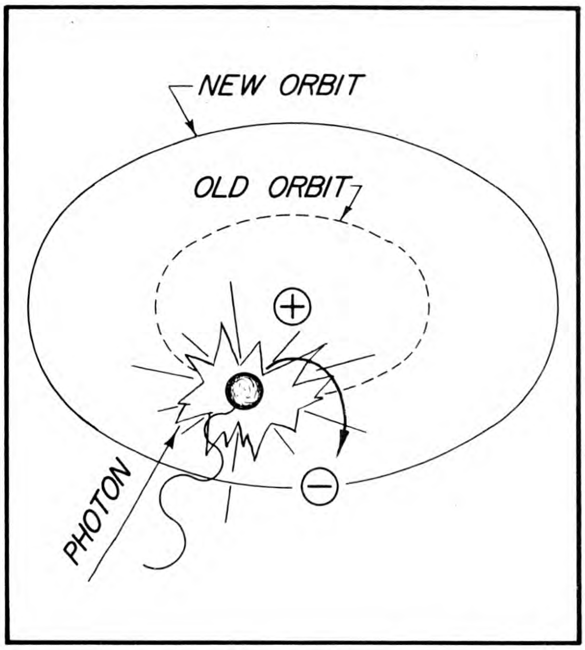

Figure 1-2.—Excitation by a photon.

Once the electron has been elevated to an energy level higher than the lowest possible energy level, the atom is said to be in an excited state. The electron will not remain in this excited condition for more than a fraction of a second before it will radiate the excess energy and return to a lower energy orbit. To illustrate this principle, assume that a normal electron has just received a photon of energy sufficient to raise it from the first to the third energy level. In a short period of time the electron may jump back to the first level emitting a new photon identical to the one it received.

A second alternative would be for the electron to return to the lower level in two jumps; from the third to the second, and then from the second to the first. In this case the electron would emit two photons, one for each jump. Each of these photons would have less energy than the original photon which excited the electron.

This principle is used in the fluorescent light where ultraviolet light photons, which are not visible to the human eye, bombard a phosphor coating on the inside of a glass tube. The phosphor electrons, in returning to their normal orbits, emit photons of light that are visible. By using the proper chemicals for the phosphor coating, any color of light may be obtained, including white. This same principle is also used in lighting up the screen of a television picture tube.

The basic principles just developed apply equally well to the atoms of more complex elements. In atoms containing two or more electrons, the electrons interact with each other and the exact path of any one electron is very difficult to predict. However, each electron lies in a specific energy band and the orbits will be considered as an average of the electron's position.

Q7. **What is energy of motion called?**

Q8. **How is invisible light changed to visible light in a flourescent light?**

Shells and Subshells

The difference between the atoms, insofar as their chemical activity and stability are concerned, is dependent upon the number and position of the electrons included within the atom. How are these electrons positioned within the atom? In general, the electrons reside in groups of orbits called shells. These shells are elliptically shaped and are assumed to be located at fixed intervals. Thus, the shells are arranged in steps that correspond to fixed energy levels. The shells, and the number of electrons required to fill them, may be predicted by the employment of Pauli's exclusion principle. Simply stated, this principle specifies that each shell will contain a maximum of $2n^2$ electrons, where n corresponds to the shell number starting with the one closest to the nucleus. By this principle, the second shell, for example, would contain $2(2)^2$ or 8 electrons when full.

In addition to being numbered, the shells are also given letter designations, as pictured in figure 1-3. Starting with the shell closest to the nucleus and progressing outward, the shells are labeled K, L, M, N, O, P, and Q, respectively. The shells are considered to be full, or complete, when they contain the following quantities of electrons: two in the K shell, eight in the L shell, eighteen in the M shell, and so on, in accordance with the exclusion principle. Each of these shells is a major shell and can be divided into subshells, of which there are four, labeled s, p, d, and f. Like the major shells, the subshells are also limited as to the number of electrons which they can contain. Thus, the "s" subshell is complete when it contains two electrons, the "p" subshell when it contains six, the "d" subshell when it contains ten, and the "f" subshell when it contains fourteen electrons.

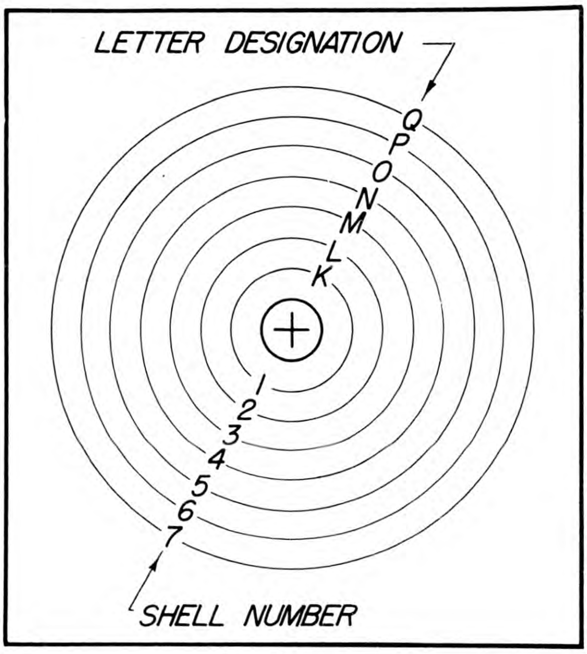

Figure 1-3.—Shell designation.

Inasmuch as the K shell can contain no more than two electrons, it must have only one subshell, the s subshell. The M shell is composed of three subshells: s, p, and d. If the electrons in the s, p, and d subshells are added, their total is found to be 18, the exact number required to fill the M shell. Notice the electron configuration for copper illustrated in figure 1-4. The copper atom contains 29 electrons, which completely fill the first three shells and subshells, leaving one electron in the "s" subshell of the N shell.

Valence

The number of electrons in the outermost shell determines the valence of an atom. For this reason, the outer shell of an atom is called the VALENCE SHELL; and the electrons contained in this shell are called VALENCE ELECTRONS. The valence of an atom determines its ability to gain or lose an electron, which in turn determines the chemical and electrical properties of the atom. An atom that is lacking only one or two electrons from its outer shell will easily gain electrons to complete its shell, but a large amount of energy is required to free any of its electrons. An atom having a relatively small

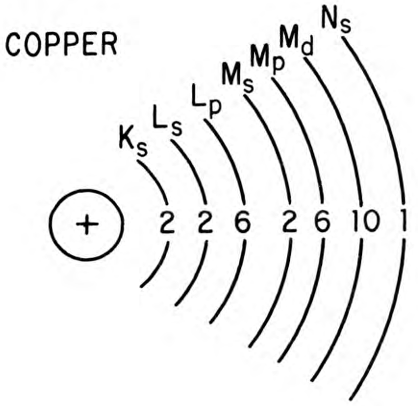

Figure 1-4.—Copper atom.

A7. Kinetic Energy

A8. Invisible light photons (ultraviolet) bombard the phosphor atom in the light tube. The phosphor atoms emit visible light photons

---

number of electrons in its outer shell in comparison to the number of electrons required to fill the shell will easily lose these valence electrons. The valence shell always refers to the outermost shell.

Q9. What determines the valence of an atom?

Ionization

When the atom loses electrons or gains electrons in this process of electron exchange, it is said to be IONIZED. For ionization to take place there must be a transfer of energy which results in a change in the internal energy of the atom. An atom having more than its normal amount of electrons acquires a negative charge, and is called a NEGATIVE ION. The atom that gives up some of its normal electrons is left with less negative charges than positive charges and is called a POSITIVE ION. Thus, ionization is the process by which an atom loses or gains electrons.

Q10. What is an ion?

CONDUCTORS, SEMICONDUCTORS, AND INSULATORS

In this study of electricity and electronics, the association of matter and electricity is important. Since every electronical device is constructed of parts made from ordinary matter, the effects of electricity on matter must be well understood. As a means of accomplishing this, all elements of which matter is made may be placed into one of three categories: CONDUCTORS, SEMICONDUCTORS, and INSULATORS, depending on their ability to conduct an electric current. CONDUCTORS are elements which conduct electricity very readily. INSULATORS have an extremely high resistance to the flow of electricity. All matter between these two extremes may be called SEMICONDUCTORS.

The electron theory states that all matter is composed of atoms and the atoms are composed of smaller particles called protons, electrons, and neutrons. The electrons orbit the nucleus which contains the protons and neutrons. It is the valence electrons that we are most concerned with in electricity. These are the electrons which are easiest to break loose from their parent atom. Normally, conductors have three or less valence electrons; insulators have five or more valence electrons; and semiconductors usually have four valence electrons.

The electrical conductivity of matter is dependent upon the atomic structure of the material from which the conductor is made. In any solid material, such as copper, the atoms which make up the molecular structure are bound firmly together. At room temperature copper will contain a considerable amount of heat energy. Since heat energy is one method of removing electrons from their orbits, copper will contain many free electrons that can move from atom to atom. When not under the influence of an external force, these electrons move in a haphazard manner within the conductor. This movement is equal in all directions so that electrons are not lost or gained by any part of the conductor. When controlled by an external force, the electrons move generally in the same direction. The effect of this movement is felt almost instantly from one end of the conductor to the other. This electron movement is called an ELECTRIC CURRENT.

Some metals are better conductors of electricity than others. Silver, copper, gold, and aluminum are materials with many free electrons and make good conductors. Silver is the best conductor, followed by copper, gold, and aluminum. Copper is used more often than silver because of cost. Aluminum is used where weight is a major consideration, such as in high-tension power lines, with long spans between supports. Gold is used where oxidation or corrosion is a consideration and a good conductivity is required. The ability of a conductor to handle current also depends upon its physical dimensions. Conductors are usually found in the form of wire, but may be in the form of bars, tubes, or sheets.

Nonconductors have few free electrons. These materials are called INSULATORS. Some examples of these materials are rubber, plastic, enamel, glass, dry wood, and mica. Just as there is no perfect conductor, neither is there a perfect insulator.

Some materials are neither good conductors nor good insulators, since their electrical characteristics fall between those of conductors and insulators. These in-between materials are classified as SEMICONDUCTORS. Germanium and silicon are two common semiconductors used in solid-state devices.

Q11. What determines whether a substance is a conductor or an insulator?

ELECTROSTATICS

Electrostatics (electricity at rest) is a subject with which most persons entering the field of electricity and electronics are somewhat familiar. For example, the way a person's hair stands on end after a vigorous rubbing is an effect of electrostatics. While pursuing the study of electrostatics, you will gain a better understanding of this common occurrence. Of even greater significance, the study of electrostatics will provide you with the opportunity to gain important background knowledge and to develop concepts which are essential to the understanding of electricity and electronics.

Interest in the subject of static electricity can be traced back to the Greeks. Thales of Miletus, a Greek philosopher and mathematician, discovered that when an amber rod is rubbed with fur, the rod has the amazing characteristic of attracting some very light objects such as bits of paper and shavings of wood.

About 1600, William Gilbert, an English scientist, made a study of other substances which had been found to possess qualities of attraction similar to amber. Among these were glass, when rubbed with silk, and ebonite, when rubbed with fur. Gilbert classified all the substances which possessed properties similar to those of amber as electrics, a word of Greek origin meaning amber.

Because of Gilbert's work with electrics, a substance such as amber or glass when given a vigorous rubbing was recognized as being ELECTRIFIED, or CHARGED with electricity.

In the year 1733, Charles Dufay, a French scientist, made an important discovery about electrification. He found that when a glass rod was rubbed with fur, both the glass rod and the fur became electrified. This realization came when he systematically placed the glass rod and the fur near other electrified substances and found that certain substances which were attracted to the glass rod were repelled by the fur, and vice versa. From experiments such as this, he concluded that there must be two exactly opposite kinds of electricity.

Benjamin Franklin, American statesman, inventor, and philosopher, is credited with first using the terms POSITIVE and NEGATIVE to describe the two opposite kinds of electricity. The charge produced on a glass rod when it is rubbed with silk, Franklin labeled positive. He attached the term negative to the charge produced on the silk. Those bodies which were not electrified or charged, he called NEUTRAL.

STATIC ELECTRICITY

In a natural, or neutral state, each atom in a body of matter will have the proper number of electrons in orbit around it. Consequently, the whole body of matter composed of the neutral atoms will also be electrically neutral. In this

A 9. The number of electrons in the outer shell

A10. An atom with more or less than its normal number of electrons

A11. The number of valence electrons

---

state, it is said to have a "zero charge." Electrons will neither leave nor enter the neutrally charged body should it come in contact with other neutral bodies. If, however, any number of electrons are removed from the atoms of a body of matter, there will remain more protons than electrons and the whole body of matter will become ELECTRICALLY POSITIVE. Should the positively charged body come in contact with another body having a normal charge, or having a NEGATIVE (too many electrons) charge, an electric current will flow between them. Electrons will leave the more negative body and enter the positive body. This electron flow will continue until both bodies have equal charges. When two bodies of matter have unequal charges and are near one another, an electric force is exerted between them because of their unequal charges. However, since they are not in contact, their charges cannot equalize. The existence of such an electric force, where current cannot flow, is referred to as static electricity. ("Static" in this instance means "not moving.") It is also referred to as an electrostatic force.

One of the easiest ways to create a static charge is by friction. When two pieces of matter are rubbed together, electrons can be "wiped off" one material onto the other. If the materials used are good conductors, it is quite difficult to obtain a detectable charge on either, since equalizing currents can flow easily between the conducting materials. These currents equalize the charges almost as fast as they are created. A static charge is more easily created between nonconducting materials. When a hard rubber rod is rubbed with fur, the rod will accumulate electrons given up by the fur, as shown in figure 1-5. Since both materials are poor conductors, very little equalizing current can flow, and an electrostatic charge builds up. When the charge becomes great enough, current will flow regardless of the poor conductivity of the materials. These currents will cause visible sparks and produce a crackling sound.

Q12. How is a negative charge created in a neutral body?

Q13. How are static charges created?

Nature of Charges

When in a natural, or neutral state, an atom has an equal number of electrons and protons. Because of this balance, the net negative charge of the electrons in orbit is exactly balanced by the net positive charge of the protons in the neucleus, making the atom electrically neutral.

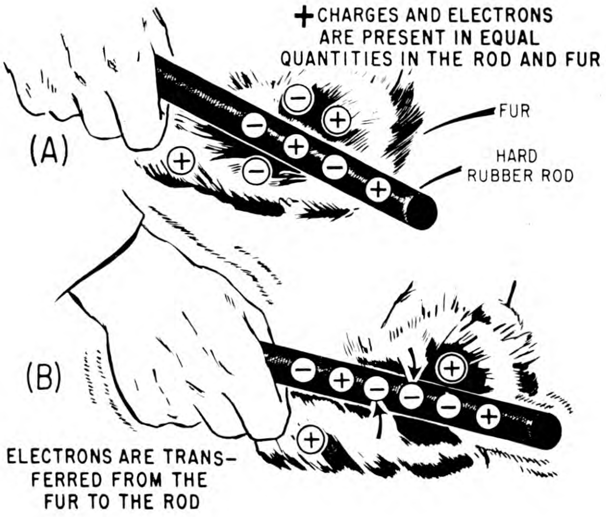
+CHARGES AND ELECTRONS ARE PRESENT IN EQUAL QUANTITIES IN THE ROD AND FUR
FUR
HARD RUBBER ROD
(A)
(B)
ELECTRONS ARE TRANSFERRED FROM THE FUR TO THE ROD

Figure 1-5.—Producing static electricity by friction.

An atom becomes a positive ion whenever it loses an electron, and has an overall positive charge. Conversely, whenever an atom acquires an extra electron, it becomes a negative ion and has a negative charge.

Due to normal molecular activity, there are always ions present in any material. If the number of positive ions and negative ions is equal, the material is electrically neutral. When the number of positive ions exceeds the number of negative ions, the material is positively charged. The material is negatively charged whenever the negative ions outnumber the positive ions.

Since ions are actually atoms without their normal number of electrons, it is the excess or the lack of electrons in a substance that determines its charge. In most solids, the transfer of charges is by movement of electrons rather than ions. The transfer of charges by ions will become more significant when we consider electrical activity in liquids and gases. At this time, we will discuss electrical behavior in terms of electron movement.

Q14. What is the electrical charge of an atom which contains 8 protons and 11 electrons?

Charged Bodies

One of the fundamental laws of electricity is that LIKE CHARGES REPEL EACH OTHER and UNLIKE CHARGES ATTRACT EACH OTHER. A positive charge and negative charge, being unlike, tend to move toward each other. In the atom, the negative electrons are drawn toward the positive protons in the nucleus. This attractive force is balanced by the electron's centrifugal force caused by its rotation about the nucleus. As a result, the electrons remain in orbit and are not drawn into the nucleus. Electrons repel each other because of their like negative charges, and protons repel each other because of their like positive charges.

The law of charged bodies may be demonstrated by a simple experiment. Two pith (paper pulp) balls are suspended near one another by threads, as shown in figure 1-6.

If a hard rubber rod is rubbed with fur to give it a negative charge and is then held against the right-hand ball in part (A), the rod will give off a negative charge to the ball. The right-hand ball will have a negative charge with respect to the left-hand ball. When released, the two balls will be drawn together, as shown in figure 1-6(A). They will touch and remain in contact until the left-hand ball gains a portion of the negative charge of the right-hand ball, at which time they will swing apart as shown in figure 1-6(C). If a positive or a negative charge is placed on both balls (fig. 1-6(B)), the balls will repel each other.

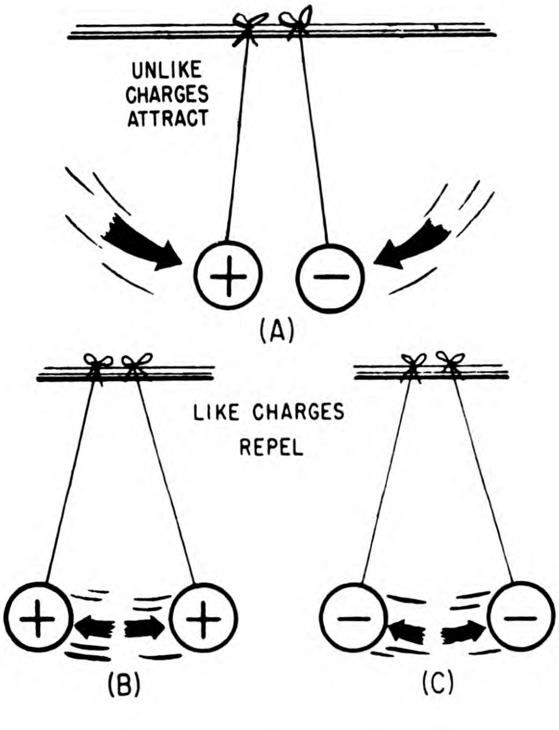

Figure 1-6.—Reaction between charged bodies.

Coulomb's Law of Charges

The relationship between attracting or repelling charged bodies was first discovered and written about by a French scientist named

A12. **Through the accumulation of excess electrons**

A13. **By friction**

A14. **Negative**

Charles A. Coulomb. Coulomb's Law states that CHARGED BODIES ATTRACT OR REPEL EACH OTHER WITH A FORCE THAT IS DIRECTLY PROPORTIONAL TO THE PRODUCT OF THEIR INDIVIDUAL CHARGES, AND IS INVERSELY PROPORTIONAL TO THE SQUARE OF THE DISTANCE BETWEEN THEM.

The amount of attracting or repelling force which acts between two electrically charged bodies in free space depends on two things–(1) their charges and (2) the distance between them.

Electric Fields

The space between and around charged bodies in which their influence is felt is called an ELECTRIC FIELD OF FORCE. It can exist in air, glass, paper, or a vacuum. ELECTROSTATIC FIELDS and DIELECTRIC FIELDS are other names used to refer to this region of force.

Fields of force spread out in the space surrounding their point of origin and, in general, DIMINISH IN PROPORTION TO THE SQUARE OF THE DISTANCE FROM THEIR SOURCE.

The field about a charged body is generally represented by lines which are referred to as ELECTROSTATIC LINES OF FORCE. These lines are imaginary and are used merely to represent the direction and strength of the field. To avoid confusion, the lines of force exerted by a positive charge are always shown leaving the charge, and for a negative charge they are shown entering. Figure 1-7 illustrates the use of lines to represent the field about charged bodies.

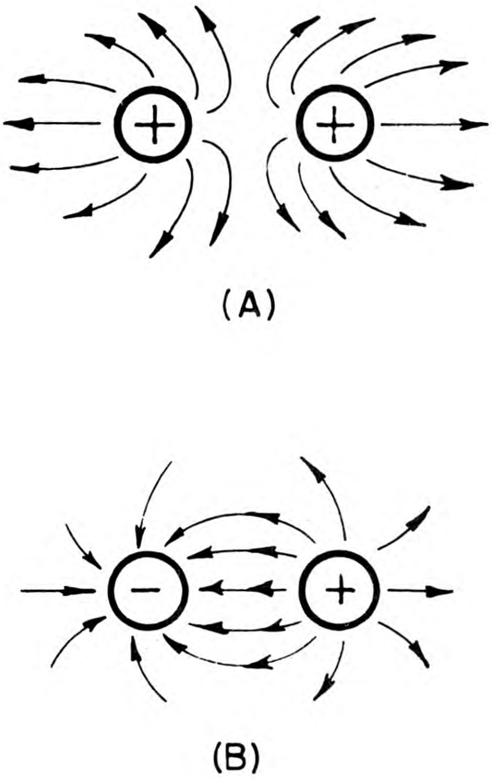

Figure 1-7.—Electrostatic lines of force.

Figure 1-7(A) represents the repulsion of like-charged bodies and their associated fields. Part (B) represents the attraction of unlike-charged bodies and their associated fields.

Q15. **What is the relationship between charged bodies?**

Q16. **What is an electrostatic field?**

Q17. **In what direction are electrostatic lines of force drawn?**

MAGNETISM

In order to properly understand the principles of electricity, it is necessary to study magnetism and the effects of magnetism on electrical equipment. Magnetism and electricity are so closely related that the study of either subject would be incomplete without at least a basic knowledge of the other.

Much of today's modern electrical and electronic equipment could not function without magnetism. Modern computers, tape recorders, and video reproduction equipment use magnetized tape. High-fidelity speakers use magnets to convert amplifier outputs into audible sound. Electrical motors use magnets to convert electrical energy into mechanical motion; generators use magnets to convert mechanical motion into electrical energy.

Q18. What are some examples of electrical equipment which use magnetism?

MAGNETIC MATERIALS

Magnetism is generally defined as that property of a material which enables it to attract pieces of iron. A material possessing this property is known as a MAGNET. The word originated with the ancient Greeks, who found stones possessing this characteristic. Materials that are attracted by a magnet, such as iron, steel, nickel, and cobalt, have the ability to become magnetized. These are called magnetic materials. Materials, such as paper, wood, glass, or tin, which are not attracted by magnets, are considered nonmagnetic. Nonmagnetic materials are not able to become magnetized.

Q19. What are magnetic materials?

Ferromagnetic Materials

The most important group of materials connected with electricity and electronics are the ferromagnetic materials. Ferromagnetic materials are those which are relatively easy to magnetize, such as iron, steel, cobalt, and the alloys Alnico and Permalloy. (An alloy is made from combining two or more elements, one of which must be a metal.) These new alloys can be very strongly magnetized, and are capable of obtaining a magnetic strength great enough to lift five hundred times their own weight.

Natural Magnets

Magnetic stones such as those found by the ancient Greeks are considered to be NATURAL MAGNETS. These stones had the ability to attract small pieces of iron in a manner similar to the magnets which are common today. However, the magnetic properties attributed to the stones were products of nature and not the result of the efforts of man. The Greeks called these substances magnetite.

The Chinese are said to have been aware of some of the effects of magnetism as early as 2600 B.C. They observed that stones similar to magnetite, when freely suspended, had a tendency to assume a nearly north and south direction. Because of the directional quality of these stones, they were later referred to as lodestones or leading stones.

Natural magnets, which presently can be found in the United States, Norway, and Sweden, no longer have any practical use, for it is now possible to easily produce more powerful magnets.

Q20. What characteristics do all ferromagnetic materials have in common?

Artificial Magnets

Magnets produced from magnetic materials are called ARTIFICIAL MAGNETS. They can be made in a variety of shapes and sizes and are used extensively in electrical apparatus. Artificial magnets are generally made from special iron or steel alloys which are usually magnetized electrically. The material to be

A15. Like charges repel, and unlike charges attract with a force directly proportional to the product of their charges and inversely proportional to the square of the distance between them

A16. The space between and around charged bodies

A17. Leaving positive, entering negative

A18. Motors, generators, speakers, computers, televisions, tape recorders, and many others

A19. Those materials that are attracted by magnets and have the ability to become magnetized

A20. The relative ease with which they are magnetized

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magnetized is inserted into a coil of insulated wire and a heavy flow of electrons is passed through the wire. Magnets can also be produced by stroking a magnetic material with magnetite or with another artificial magnet. The forces causing magnetization are represented by magnetic lines of force, very similar in nature to electrostatic lines of force.

Artificial magnets are usually classified as PERMANENT or TEMPORARY, depending on their ability to retain their magnetic properties after the magnetizing force has been removed. Magnets made from substances, such as hardened steel and certain alloys which retain a great deal of their magnetism, are called PERMANENT MAGNETS. These materials are relatively difficult to magnetize because of the opposition offered to the magnetic lines of force as the lines of force try to distribute themselves throughout the material. The opposition that a material offers to the magnetic lines of force is called RELUCTANCE. All permanent magnets are produced from materials having a high reluctance.

A material with a low reluctance, such as soft iron or annealed silicon steel, is relatively easy to magnetize but will retain only a small part of its magnetism once the magnetizing force is removed. Materials of this type that easily lose most of their magnetic strength are called TEMPORARY MAGNETS. The amount of magnetism which remains in a temporary magnet is referred to as its RESIDUAL MAGNETISM. The ability of a material to retain an amount of residual magnetism is called the RETENTIVITY of the material.

The difference between a permanent and a temporary magnet has been indicated in terms of RELUCTANCE, a permanent magnet having a high reluctance and a temporary magnet having a low reluctance. Magnets are also described in terms of the PERMEABILITY of their materials, or the ease with which magnetic lines of force distribute themselves throughout the material. A permanent magnet, which is produced from a material with a high reluctance, has a low permeability. A temporary magnet, produced from a material with a low reluctance, would have a high permeability.

Q21. What type of magnetic material should be used to make a temporary magnet?

Q22. What is retentivity?

MAGNETIC POLES

The magnetic force surrounding a magnet is not uniform. There exists a great concentration of force at each end of the magnet and a very weak force at the center. Proof of this fact can be obtained by dipping a magnet into iron filings (fig. 1-8). It is found that many filings will cling to the ends of the magnet while very few adhere to the center. The two ends, which are the regions of concentrated lines of force, are called the POLES of the magnet. Magnets have two magnetic poles and both poles have equal magnetic strength.

Law of Magnetic Poles

If a bar magnet is suspended freely on a string, as shown in figure 1-9, it will align itself in a north and south direction. When this experiment is repeated, it is found that the same pole of the magnet will always swing toward the north geographical pole of the earth. Therefore, it is called the north-seeking pole or simply the NORTH POLE. The other pole of the magnet is the south-seeking pole or the SOUTH POLE.

A practical use of the directional characteristic of the magnet is the compass, a device in which a freely rotating magnetized needle indicator points toward the North Pole. The realization that the poles of a suspended magnet always move to a definite position gives an indication that the opposite poles of a magnet have opposite magnetic polarity.

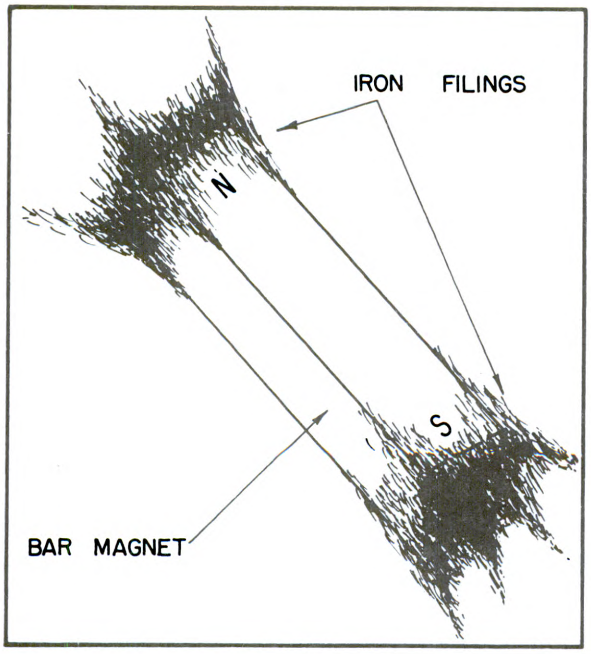

Figure 1-8.—Iron filings cling to the poles of a magnet.

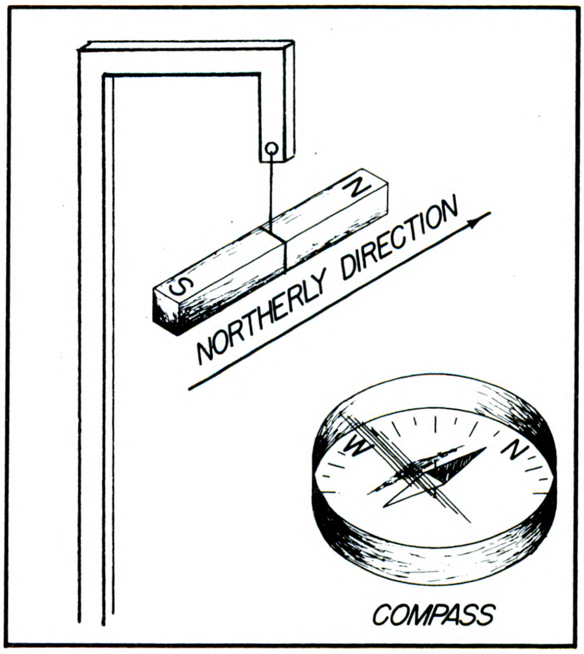

Figure 1-9.—A bar magnet acts as a compass.

The law previously stated regarding the attraction and replusion of charged bodies may also be applied to magnetism if the pole is considered as a charge. The north pole of a magnet will always be attracted to the south pole of another magnet and will show a repulsion to a north pole. The law for magnetic poles is:

Like poles repel, unlike poles attract.

Q23. How does the law of magnetic poles relate to the law of electric charges?

The Earth's Magnetic Poles

The fact that a compass needle always aligns itself in a particular direction, regardless of its

A21. A material that exhibits low reluctance, and high peremability, such as iron or soft steel

A22. The ability of a material to retain magnetism

A23. They are very similar; like charges repel, unlike charges attract–like poles repel, unlike poles attract

---

location on earth, indicates that the earth is a huge natural magnet. The distribution of the magnetic force about the earth is the same as that which might be produced by a giant bar magnet running through the center of the earth (fig. 1-10). The magnetic axis of the earth is located about 15° from its geographical axis thereby locating the magnetic poles some distance from the geographical poles. The ability of the north pole of the compass needle to point toward the north geographical pole is due to the presence of the magnetic pole nearby. This magnetic pole is named the magnetic North Pole. However, in actuality, it must have the polarity of a south magnetic pole since it attracts the north pole of a compass needle. The reason for this conflict in terminology can be traced to the early users of the compass. Knowing little about magnetic effects, they called the end of the compass needle that pointed towards the north geographical pole, the north pole of a compass. With our present knowledge of magnetism, we know the north pole of a compass needle (a small bar magnet) can be attracted only by an unlike magnetic pole, that is, a pole of south magnetic polarity.

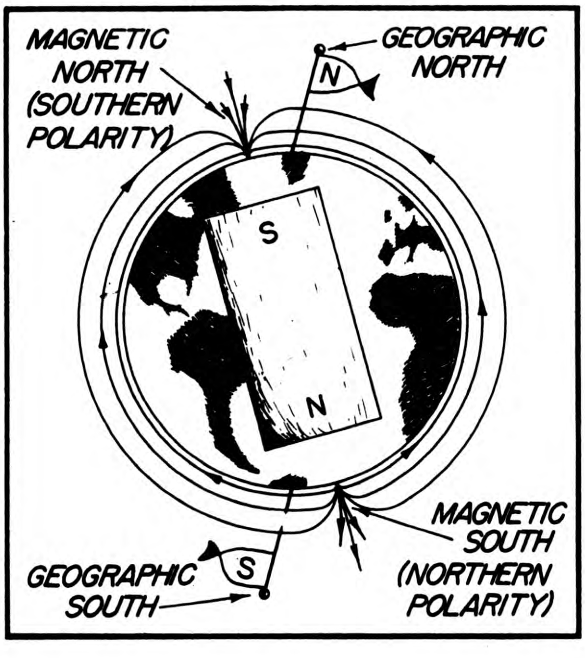
MAGNETIC NORTH (SOUTHERN POLARITY)
GEOGRAPHIC NORTH
N
S
N
MAGNETIC SOUTH (NORTHERN POLARITY)
GEOGRAPHIC SOUTH
S

Figure 1-10.—The earth is a magnet.

Q24. A compass is located at the geographical North Pole. In which direction would its needle point?

THEORIES OF MAGNETISM

Weber's Theory

A popular theory of magnetism considers the molecular alignment of the material. This is known as Weber's Theory. This theory assumes that all magnetic substances are composed of tiny molecular magnets. Any unmagnetized material has the magnetic forces of its molecular magnets neutralized by adjacent molecular magnets, thereby eliminating any magnetic effect. A magnetized material will have most of its molecular magnets lined up so that the north pole of each molecule points in one direction, and the south pole faces the opposite direction. A material with its molecules thus aligned will then have one effective north pole, and one effective south pole. An illustration of Weber's Theory is shown in figure 1-11, where a steel bar is magnetized by stroking. When a steel bar is stroked several times in the same direction by a magnet, the magnetic force from the north pole of the magnet causes the molecules to align themselves.

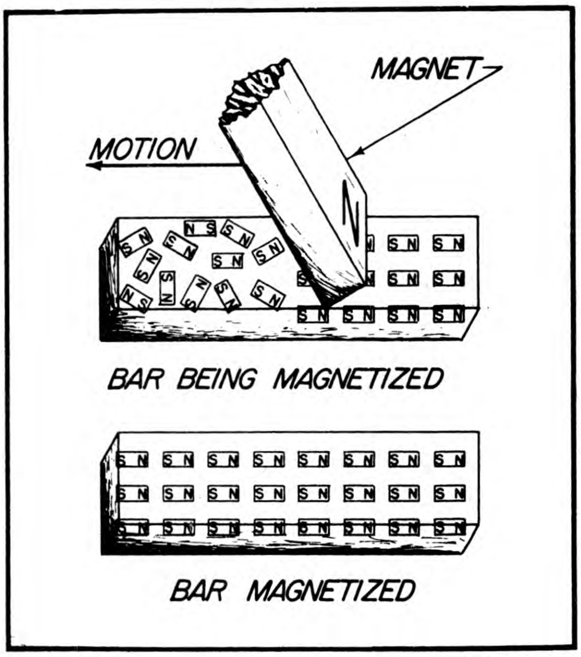
MAGNET
MOTION
N
S N
BAR BEING MAGNETIZED
BAR MAGNETIZED

Figure 1-11.—Molecular magnets.

Q25. Using Weber's molecular theory of magnetism, describe the polarity of the magnetic poles produced by stroking a magnetic material from right to left with the south pole of a magnet.

Domain Theory

A more modern theory of magnetism is based on the electron spin principle. From the study of atomic structure it is known that all matter is composed of vast quantities of atoms, each atom containing one or more orbital electrons. The electrons are considered to orbit in various shells and subshells depending upon their distance from the nucleus. The structure of the atom has previously been compared to the solar system, wherein the electrons orbiting the nucleus correspond to the planets orbiting the sun. Along with its orbital motion about the sun, each planet also revolves on its axis. It is believed that the electron also revolves on its axis as it orbits the nucleus of an atom.

It has been experimentally proven that an electron has a magnetic field about it along with an electric field. The effectiveness of the magnetic field of an atom is determined by the number of electrons spinning in each direction. If an atom has equal numbers of electrons spinning in opposite directions, the magnetic fields surrounding the electrons cancel one another, and the atom is unmagnetized. However, if more electrons spin in one direction than another, the atom is magnetized. An atom with an atomic number of 26, such as iron, has 26 protons in the nucleus and 26 revolving electrons orbiting its nucleus. If 13 electrons are spinning in a clockwise direction and 13 electrons are spinning in a counterclockwise direction, the opposing magnetic fields will be neutralized. When more than 13 electrons spin in either direction, the atom is magnetized. An example of a magnetized atom of iron is shown in figure 1-12.

Q26. What is the difference between the domain theory and Weber's theory of magnetism?

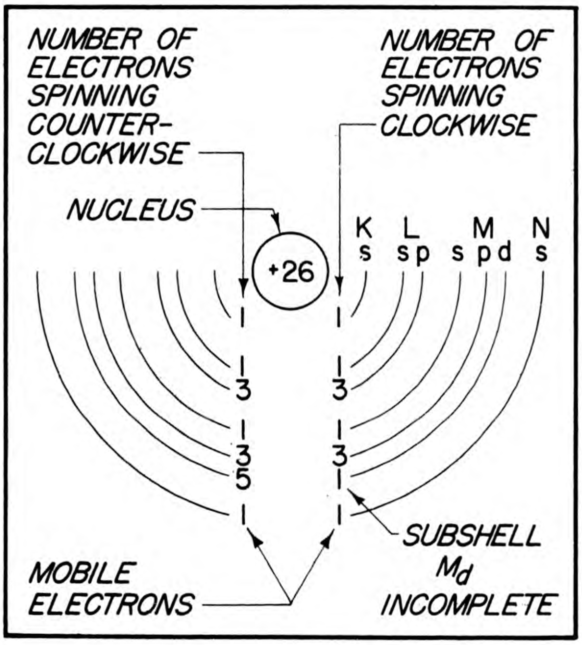
NUMBER OF ELECTRONS SPINNING COUNTER-CLOCKWISE
NUMBER OF ELECTRONS SPINNING CLOCKWISE
NUCLEUS
+26
K L M N
s sp spd s
1
1
3
1
3
5
1
1
1
3
1
3
1
1
SUBSHELL M_d INCOMPLETE
MOBILE ELECTRONS

Figure 1-12.—Iron atom.

A24. To the magnetic North Pole

A25. South pole at the right, north pole at the left

A26. The domain theory is based upon the electron spin principle; Weber's theory uses the concept of tiny molecular magnets

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MAGNETIC FIELDS

The space surrounding a magnet where magnetic forces act is known as the magnetic field.

A pattern of this directional force can be obtained by performing an experiment with iron filings. A piece of glass is placed over a bar magnet and the iron filings are then sprinkled on the surface of the glass. The magnetizing force of the magnet will be felt through the glass and each iron filing becomes a temporary magnet. If the glass is now tapped gently, the iron particles will align themselves with the magnetic field surrounding the magnet just as the compass needle did previously. The filings form a definite pattern, which is a visible representation of the forces comprising the magnetic field. Examination of the arrangements of iron filings in figure 1-13 will indicate that the magnetic field is very strong at the poles and weakens as the distance from the poles increases. It is also apparent that the magnetic field extends from one pole to the other, constituting a loop about the magnet.

Q27. Refer to figure 1-13. For what purpose would you sprinkle iron filings on the glass plate?

Q28. Refer to figure 1-13. What pattern would be formed if sawdust was sprinkled on the glass instead of iron filings?

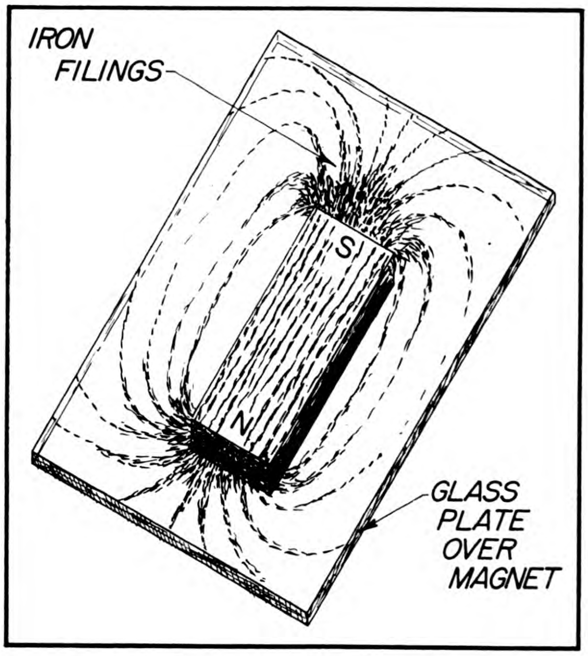

Figure 1-13.—Pattern formed by iron filings.

Lines of Force

To further describe and work with magnetic phenomena, lines are used to represent the force existing in the area surrounding a magnet (refer to fig. 1-14). These lines, called MAGNETIC LINES OF FORCE, do not actually exist but are imaginary lines used to illustrate and describe the pattern of the magnetic field. The magnetic lines of force are assumed to emanate from the north pole of a magnet, pass through the surrounding space, and enter the south pole. The lines of force then travel inside the magnet from the south pole to the north pole, thus completing a closed loop.

When two magnetic poles are brought close together, the mutual attraction or repulsion of the poles produces a more complicated pattern than that of a single magnet. These magnetic lines of force can be plotted by placing a compass at various points throughout the magnetic field, or they can be roughly illustrated by the use of iron filings as before. A diagram of magnetic poles placed close together is shown in figure 1-15.

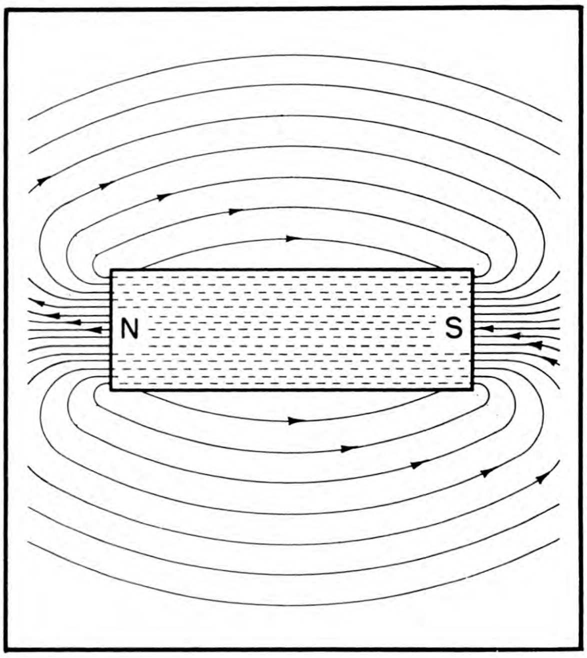

Figure 1-14.—Bar magnet showing lines of force.

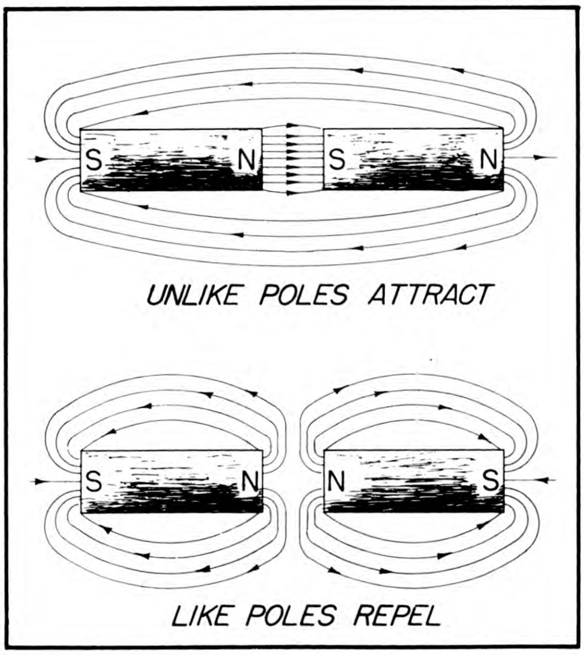

Figure 1-15.—Magnetic poles in close proximity.

Although magnetic lines of force are imaginary, a simplified version of many magnetic phenomena can be explained by assuming the magnetic lines to have certain real properties. The lines of force can be compared to rubber bands which stretch outward when a force is exerted upon them and contract when the force is removed. The characteristics of magnetic lines of force can be described as follows:

1. Magnetic lines of force are continuous and will always form closed loops.
2. Magnetic lines of force will never cross one another.
3. Parallel magnetic lines of force traveling in the same direction repel one another. Parallel magnetic lines of force traveling in opposite directions tend to unite with each other and form into single lines traveling in a direction determined by the magnetic poles creating the lines of force.
4. Magnetic lines of force tend to shorten themselves. Therefore, the magnetic lines of force existing between two unlike poles cause the poles to be pulled together.
5. Magnetic lines of force pass through all materials, both magnetic and nonmagnetic.
6. Magnetic lines of force always enter or leave a magnetic material at right angles to the surface.

Q29. What is a magnetic line of force?

Q30. In what way do magnetic lines of force differ from electrostatic lines of force?

MAGNETIC EFFECTS

MAGNETIC FLUX. The total number of magnetic lines of force leaving or entering the pole of a magnet is called MAGNETIC FLUX.

A27. **To enable you to "see" the magnetic field**

A28. **No specific pattern, sawdust is a nonmagnetic material**

A29. **An imaginary line used to illustrate magnetic effects**

A30. **Electrostatic lines of force do not form closed loops**

The number of flux lines per unit area is known as FLUX DENSITY.

FIELD INTENSITY. The intensity of a magnetic field is directly related to the magnetic force exerted by the field.

ATTRACTION/REPULSION. The intensity of attraction or repulsion between magnetic poles may be described by a law almost identical to Coulomb's Law of Charged Bodies. The force between two poles is directly proportional to the product of the pole strengths and inversely proportional to the square of the distance between the poles.

Magnetic Induction

It has been previously stated that all substances that are attracted by a magnet are capable of becoming magnetized. The fact that a material is attracted by a magnet indicates the material must itself be a magnet at the time of attraction.

With the knowledge of magnetic fields and magnetic lines of force developed up to this point, it is simple to understand the manner in which a material becomes magnetized when brought near a magnet. As an iron nail is brought close to a bar magnet (fig. 1-16), some flux lines emanating from the north pole of the magnet pass through the iron nail in completing their magnetic path. Since magnetic lines of force travel inside a magnet from the south pole to the north pole, the nail will be magnetized in such a polarity that its south pole will be adjacent to the north pole of the bar magnet. There is now an attraction between the two magnets.

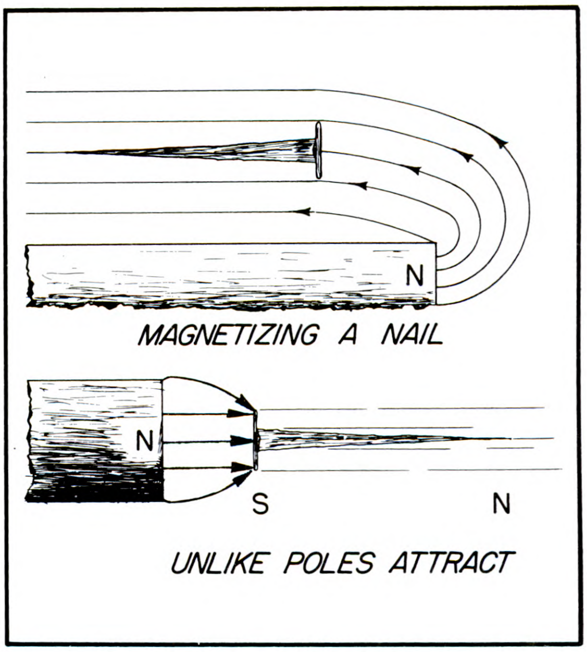

Figure 1-16.—Magnetized nail.

If another nail is brought in contact with the end of the first nail, it would be magnetized by induction. This process could be repeated until the strength of the magnetic flux weakens as distance from the bar magnet increases. However, as soon as the first iron nail is pulled away from the bar magnet, all the nails will fall. The reason being that each nail becomes a temporary magnet, and as soon as the magnetizing force is removed, their domains once again assume a random distribution.

Magnetic induction will always produce a pole polarity on the material being magnetized opposite that of the adjacent pole of the magnetizing force. It is sometimes possible to bring a weak north pole of a magnet near a strong magnet north pole and note attraction between the poles. The weak magnet, when placed within the magnetic field of the strong magnet, has its magnetic polarity reversed by the field of the stronger magnet. Therefore, it is attracted to the opposite pole. For this reason, you must keep a very weak magnet, such as a compass needle, away from a very strong magnet.

Magnetism can be induced in a magnetic material by several means. The magnetic material may be placed in the magnetic field, brought into contact with a magnet, or stroked by a magnet. Stroking and contact both indicate actual contact with the material but are considered in magnetic studies as magnetizing by INDUCTION.

Magnetic Shielding

There is no known INSULATOR for magnetic flux. If a nonmagnetic material is placed in a magnetic field, there is no appreciable change in flux—that is, the flux penetrates the nonmagnetic material. For example, a glass plate placed between the poles of a horseshoe magnet will have no appreciable effect on the field although glass itself is a good insulator in an electric circuit. If a magnetic material (for example, soft iron) is placed in a magnetic field, the flux may be redirected to take advantage of the greater permeability of the magnetic material, as shown in figure 1-17. Permeability, as discussed earlier, is the quality of a substance which determines the ease with which it can be magnetized.

The sensitive mechanisms of electric instruments and meters can be influenced by stray magnetic fields which will cause errors in their readings. Because instrument mechanisms cannot be insulated against magnetic flux, it is necessary to employ some means of directing the flux around the instrument. This is accomplished by placing a soft-iron case, called a MAGNETIC SCREEN or SHIELD, about the instrument. Because the flux is established more readily through the iron (even though the path is longer) than through the air inside the case, the instrument is effectively shielded, as shown by the watch and soft-iron shield in figure 1-18.

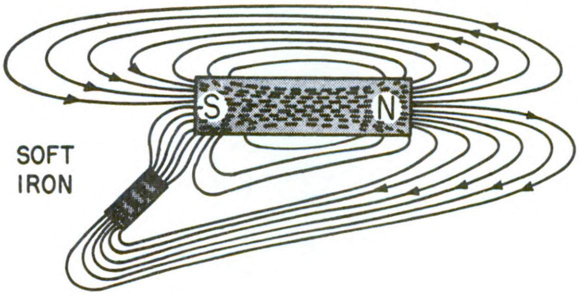

Figure 1-17.—Effects of a magnetic substance in a magnetic field.

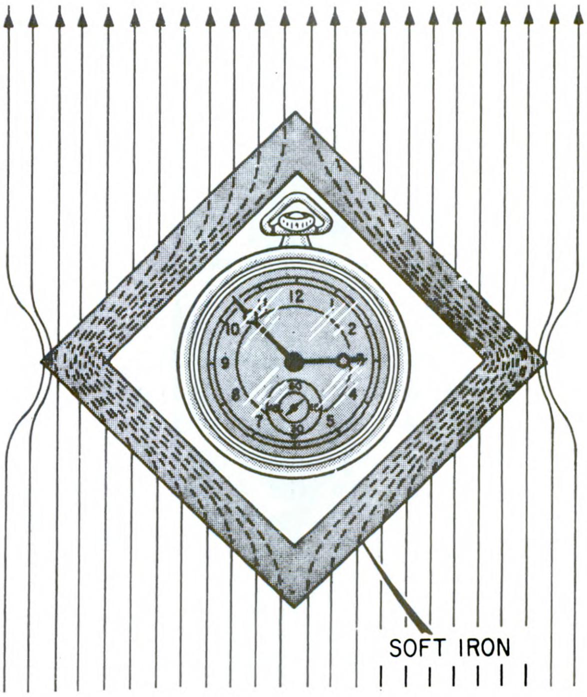

Figure 1-18.—Magnetic shield.

MAGNETIC SHAPES

Because of the many uses of magnets, they are found in various shapes and sizes. However, magnets usually come under one of three general classifications: bar magnets, horseshoe magnets, or ring magnets.

The bar magnet is most often used in schools and laboratories for studying the properties and effects of magnetism. In the preceding material, the bar magnet proved very helpful in demonstrating magnetic effects.

Another type of magnet is the ring magnet, which is used for computer memory cores. A common application for a temporary ring magnet would be the shielding of electrical instruments.

The shape of the magnet most frequently used in electrical and electronic equipment is called the horseshoe magnet. A horseshoe magnet is similar to a bar magnet but is bent in the shape of a horseshoe. The horseshoe magnet provides much more magnetic strength than a bar magnet of the same size and material because of the closeness of the magnetic poles. The magnetic strength from one pole to the other is greatly increased due to the concentration of the magnetic field in a smaller area. Electrical measuring devices quite frequently use horseshoe-type magnets.

CARE OF MAGNETS

A piece of steel that has been magnetized can lose much of its magnetism by improper handling. If it is jarred or heated, there will be a disalignment of its domains resulting in the loss of some of its effective magnetism. Had this piece of steel formed the horseshoe magnet of a meter, the meter would no longer be operable or would give inaccurate readings. Therefore, care must be exercised when handling instruments containing magnets. Severe jarring or subjecting the instrument to high temperatures will damage the device.

A magnet may also become weakened from loss of flux. Thus, when storing magnets, one should always try to avoid excess leakage of magnetic flux. A horseshoe magnet should always be stored with a keeper, a soft iron bar used to join the magnetic poles. By using the keeper while the magnet is being stored, the magnetic flux will continuously circulate through the magnet and not leak off into space.

When bar magnets are stored, the same principle must be remembered. Therefore, bar magnets should always be stored in pairs with a north pole and a south pole placed together. This provides a complete path for the magnetic flux without any flux leakage.

Q31. How should a delicate instrument be protected from a magnetic field?

Q32. How should bar magnets be stored?

ELECTRICAL ENERGY

In the field of physical science, work must be defined as THE PRODUCT OF FORCE AND DISPLACEMENT. That is, the force applied to move an object and the distance the object is moved are the factors of work performed.

It is important to notice that no work is accomplished unless the force applied causes a change in the position of a stationary object, or a change in the velocity of a moving object. A worker may tire by pushing against a heavy wooden crate, but unless the crate moves, no work will be accomplished.

ENERGY

In our study of energy and work, we must define energy as THE ABILITY TO DO WORK. In order to perform any kind of work, energy must be expended (converted from one form to another). Energy supplies the required force, or power, whenever any work is accomplished.

One form of energy is that which is contained by an object of motion. When a hammer is set in motion in the direction of a nail, it possesses energy of motion. As the hammer strikes the nail, the energy of motion is converted into work as the nail is driven into the wood. The distance the nail is driven into the wood depends on the velocity of the hammer at the time it strikes the nail. Energy contained by an object due to its motion is called KINETIC ENERGY. Assume that the hammer is suspended by a string in a position one meter above a nail. As a result of gravitational attraction, the hammer will experience a force pulling it downward. If the string is suddenly cut, the force of gravity will pull the hammer downward against the nail, driving it into the wood. While the hammer is suspended above the nail it has ability to do work because of its elevated position in the earth's gravitational field. Since energy is the ability to do work, the hammer contains energy.

Energy contained by an object due to its position is called POTENTIAL ENERGY. The amount of potential energy available is equal to the product of the force required to elevate the hammer and the height to which it is elevated.

Another example of potential energy is that contained in a tightly coiled spring. The amount of energy released when the spring unwinds depends on the amount of force required to wind the spring initially.

Q33. What is the definition of energy?

Q34. What type of energy does a rolling stone have?

Q35. What kind of energy does the stone have if it is at rest at the top of a hill?

Electrical Charges

From the previous study of electrostatics you learned that a field of force exists in the space surrounding any electrical charge. The strength of the field is directly dependent on the force of the charge.

The charge of one electron might be used as a unit of electrical charge, since charges are created by displacement of electrons; but the charge of one electron is so small that it is impractical to use. The practical unit adopted for measuring charges is the COULOMB, named after the scientist Charles Coulomb. One coulomb is equal to the charge of 6,280,000,000,000,000,000 (six quintillion two hundred and eighty quadrillion) or (6.28×10^{18}) electrons.

When a charge of one coulomb exists between two bodies, one unit of electrical potential energy exists, which is called the difference of potential between the two bodies. This is referred to as ELECTROMOTIVE FORCE, or VOLTAGE, and the unit of measure is the VOLT.

Electrical charges are created by the displacement of electrons, so that there exists an excess of electrons at one point, and a deficiency at another point. Consequently, a charge must always have either a negative or positive polarity. A body with an excess of electrons is considered to be negative, whereas a body with a deficiency of electrons is positive.

A difference of potential can exist between two points, or bodies, only if they have different charges. In other words, there is no difference in potential between two bodies if both have a deficiency of electrons to the same degree. If, however, one body is deficient of 6 coulombs (representing 6 volts), and the other is deficient by 12 coulombs (representing 12 volts), there is a difference of potential of 6 volts. The body with the greater deficiency is positive with respect to the other.

In most electrical circuits only the difference of potential between two points is of importance and the absolute potentials of the points are of little concern. Very often it is convenient to use one standard reference for all of the various potentials throughout a piece of equipment. For this reason, the potentials at various points in a circuit are generally measured with respect to the metal chassis on which all parts of the circuit are mounted. The chassis is considered to be at zero potential and all other potentials are either positive or negative with respect to the chassis. When used as the reference point, the chassis is said to be at GROUND POTENTIAL.

Occasionally, rather large values of voltage may be encountered, in which case the volt becomes too small a unit for convenience. In a

A31. **By shielding or surrounding the instrument with a soft iron case, called a magnetic shield or screen**

A32. **In pairs, with opposite poles together to provide a complete path for magnetic flux**

A33. **The ability to do work**

A34. **Kinetic energy**

A35. **Potential energy**

situation of this nature, the kilovolt (kV), meaning 1,000 volts, is frequently used. As an example, 20,000 volts would be written as 20 kV. In other cases, the volt may be too large a unit, as when dealing with very small voltages. For this purpose the millivolt (mV), meaning one-thousandth of a volt, and the microvolt (μV), meaning one-millionth of a volt, are used. For example, 0.001 volt would be written as 1 mV, and 0.000025 volt would be written as 25 μV. See Appendix II for exponential symbology.

When a difference in potential exists between two charged bodies that are connected by a conductor, electrons will flow along the conductor. This flow is from the negatively charged body to the positively charged body, until the two charges are equalized and the potential difference no longer exists.

An anology of this action is shown in the two water tanks connected by a pipe and valve in figure 1-19. At first the valve is closed and all the water is in tank A. Thus, the water pressure across the valve is at maximum. When the valve is opened, the water flows through the pipe from A to B until the water level becomes the same in both tanks. The water then stops flowing in the pipe, because there is no longer a difference in water pressure between the two tanks.

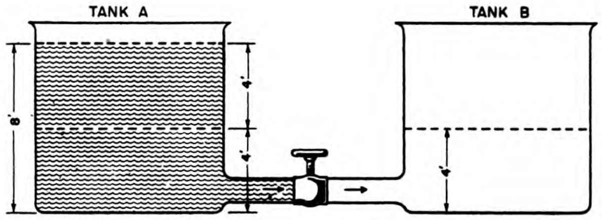

Figure 1-19.—Water analogy of electric difference of potential.

Electron movement through an electric circuit is directly proportional to the difference in potential or electromotive force (emf), across the circuit, just as the flow of water through the pipe in figure 1-19 is directly proportional to the difference in water level in the two tanks.

A fundamental law of electricity is that the ELECTRON FLOW IS DIRECTLY PROPORTIONAL TO THE APPLIED VOLTAGE. If the voltage is increased, the flow is increased. If the voltage is decreased, the flow is decreased.

Q36. **What term describes voltage or emf?**

Q37. **Convert 2.1 kV to volts.**

Q38. **Express the following in more simple terms. (a) 250,000 volts, (b) 25,000,000 microvolts, (c) 0.001 millivolt**

HOW VOLTAGE IS PRODUCED

It has been demonstrated that a charge can be produced by rubbing a rubber rod with fur. Because of the friction involved, the rod acquires electrons from the fur, making it negative;

the fur becomes positive due to the loss of electrons. These quantities of charge constitute a difference of potential between the rod and the fur. The electrons which make up this difference of potential are capable of doing work if a discharge is allowed to occur.

To be a practical source of voltage, the potential difference must not be allowed to dissipate, but must be maintained continuously. As one electron leaves the concentration of negative charge, another must be immediately provided to take its place or the charge will eventually diminish to the point where no further work can be accomplished. A VOLTAGE SOURCE, therefore, is a device which is capable of supplying and maintaining voltage while some type of electrical apparatus is connected to its terminals. The internal action of the source is such that electrons are continuously removed from one terminal, keeping it positive, and simultaneously supplied to the second terminal which maintains a negative charge.

Presently, there are six known methods for producing a voltage or electromotive force (emf). Some of these methods are more widely used than others, and some are used mostly for specific applications. Following is a list of the six known methods of producing a voltage.

1. FRICTION–Voltage produced by rubbing certain materials together.

2. PRESSURE (piezoelectricity)–Voltage produced by squeezing crystals of certain substances.

3. HEAT (thermoelectricity)–Voltage produced by heating the joint (junction) where two unlike metals are joined.

4. LIGHT (photoelectricity)–Voltage produced by light striking photosensitive (light sensitive) substances.

5. CHEMICAL ACTION–Voltage produced by chemical reaction in a battery cell.

6. MAGNETISM–Voltage produced in a conductor when the conductor moves through a magnetic field, or a magnetic field moves through the conductor in such a manner as to cut the magnetic lines of force of the field.

Voltage Produced by Friction

The first method discovered for creating a voltage was that of generation by friction. The development of charges by rubbing a rod with fur is a prime example of the way in which a voltage is generated by friction. Because of the nature of the materials with which this voltage is generated, it cannot be conveniently used or maintained. For this reason, very little practical use has been found for voltages generated by this method.

In the search for methods to produce a voltage of a larger amplitude and of a more practical nature, machines were developed in which charges were transferred from one terminal to another by means of rotating glass discs or moving belts. The most notable of these machines is the Van de Graaff generator. It is used today to produce potentials in the order of millions of volts for nuclear research. As these machines have little value outside the field of research, their theory of operation will not be described here.

Q39. A device which supplies a voltage is commonly referred to by what name?

Voltage Produced by Pressure

One specialized method of generating an emf utilizes the characteristics of certain ionic crystals such as quartz, Rochelle salts, and tourmaline. These crystals have the remarkable ability to generate a voltage whenever stresses are applied to their surfaces. Thus, if a crystal of quartz is squeezed, charges of opposite polarity will appear on two opposite surfaces of the crystal. If the force is reversed and the crystal is stretched, charges will again appear, but will be of the opposite polarity from those produced by squeezing. If a crystal of this type is given a vibratory motion, it will produce a voltage of reversing polarity between two of its sides. Quartz or similar crystals can thus be used to convert mechanical energy into electrical energy. This phenomenon, called the PIEZOELECTRIC

A36. Difference of potential

A37. 2100 volts

A38. (a) 250 kV, (b) 25 V, (c) 1μV

A39. A voltage source

EFFECT, is shown in figure 1-20. Some of the common devices that make use of piezoelectric crystals are microphones, phonograph cartridges, and oscillators used in radio transmitters, radio receivers, and sonar equipment. This method of generating an emf is not suitable for applications having large voltage or power requirements, but is widely used in sound and communications systems where small signal voltages can be effectively used.

Crystals of this type also possess another interesting property, the "converse piezoelectric effect." That is, they have the ability to convert electrical energy into mechanical energy. A voltage impressed across the proper surfaces of the crystal will cause it to expand or contract its surfaces in response to the voltage applied.

Voltage Produced by Heat

When a length of metal, such as copper, is heated at one end, electrons tend to move away from the hot end toward the cooler end. This is true of most metals. However, in some metals, such as iron, the opposite takes place and electrons tend to move TOWARD the hot end. These characteristics are illustrated in figure 1-21. The negative charges (electrons) are moving through the copper away from the heat and through the iron toward the heat. They cross from the iron to the copper through the current meter to the iron at the cold junction. This device is generally referred to as a THERMOCOUPLE.

Thermocouples have somewhat greater power capacities than crystals, but their capacity is still very small if compared to some other sources. The thermoelectric voltage in a thermocouple depends mainly on the difference in temperature between the hot and cold junctions. Consequently, they are widely used to measure temperature, and as heat-sensing devices in automatic temperature control equipment.

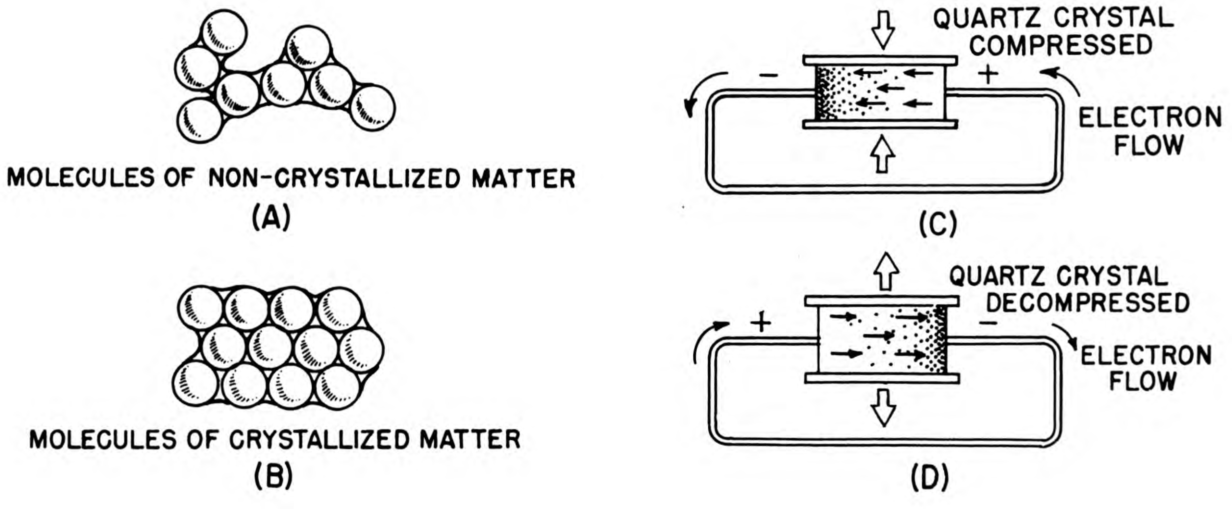
MOLECULES OF NON-CRYSTALLIZED MATTER
(A)
MOLECULES OF CRYSTALLIZED MATTER
(B)
QUARTZ CRYSTAL COMPRESSED
–
+
ELECTRON FLOW
(C)
QUARTZ CRYSTAL DECOMPRESSED
+
–
ELECTRON FLOW
(D)

Figure 1-20.—(A) Noncrystallized structure; (B) crystallized structure; (C) compression of a crystal; (D) decompression of a crystal.

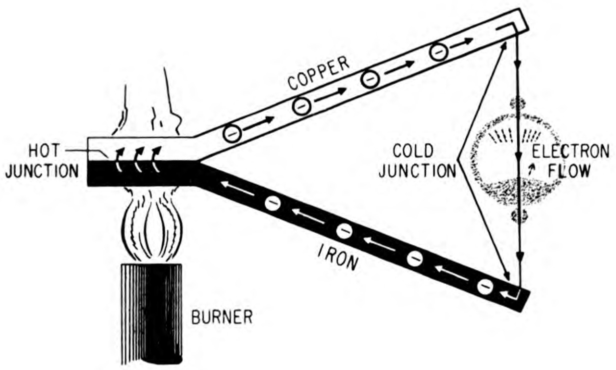
COPPER
HOT JUNCTION
COLD JUNCTION
ELECTRON FLOW
IRON
BURNER

Figure 1-21.—Voltage produced by heat.

Thermocouples generally can be subjected to much greater temperatures than ordinary thermometers, such as the mercury or alcohol types.

Voltage Produced by Light

When light strikes the surface of a substance, it may dislodge electrons from their orbits around the surface atoms of the substance. This occurs because light has energy, the same as any moving force.

Some substances, mostly metallic ones, are far more sensitive to light than others. That is, more electrons will be dislodged and emitted from the surface of a highly sensitive metal, with a given amount of light, than will be emitted from a less senstive substance. Upon losing electrons, the photosensitive (light-sensitive) metal becomes positively charged, and an electric force is created. Voltage produced in this manner is referred to as a PHOTOELECTRIC VOLTAGE.

The photosensitive materials most commonly used to produce a photoelectric voltage are various compounds of silver oxide or copper oxide. A complete device which operates on the photoelectric principle is referred to as a "photoelectric cell." There are many different sizes and types of photoelectric cells in use, and each serves the special purpose for which it is designed. Nearly all, however, have some of the basic features of the photoelectric cells shown in figure 1-22.

The cell (fig. 1-22(A)) has a curved light-sensitive surface focused on the central anode. When light from the direction shown strikes the sensitive surface, it emits electrons toward the anode. The more intense the light, the greater the number of electrons emitted. When a wire is connected between the filament and the back, or dark side of the cell, the accumulated electrons will flow to the dark side. These electrons will eventually pass through the metal of the reflector and replace the electrons leaving the light-sensitive surface. Thus, light energy is converted to a flow of electrons, and a usuable current is developed.

The cell (fig. 1-22(B)) is constructed in layers. A base plate of pure copper is coated with light-sensitive copper oxide. An extremely thin semitransparent layer of metal is placed over the copper oxide. This additional layer serves two purposes:

1. It permits the penetration of light to the copper oxide.

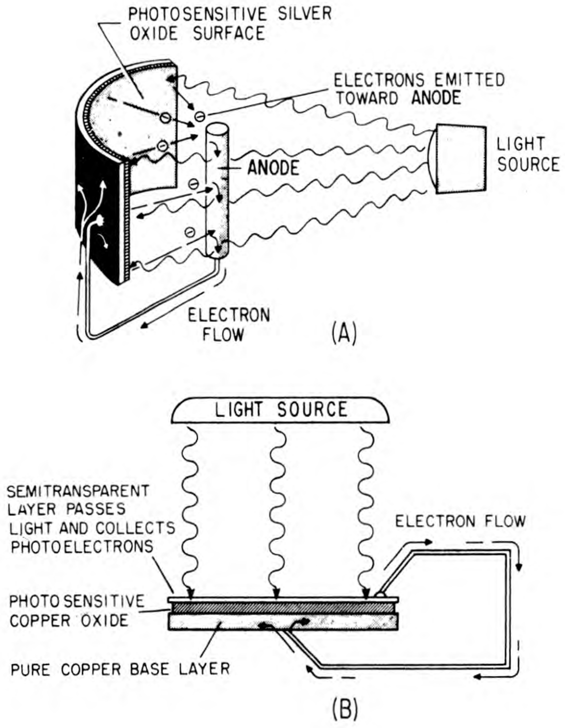
PHOTOSENSITIVE SILVER OXIDE SURFACE
ELECTRONS EMITTED TOWARD ANODE
LIGHT SOURCE
ANODE
ELECTRON FLOW
(A)
LIGHT SOURCE
SEMITRANSPARENT LAYER PASSES LIGHT AND COLLECTS PHOTOELECTRONS
ELECTRON FLOW
PHOTOSENSITIVE COPPER OXIDE
PURE COPPER BASE LAYER
(B)

Figure 1-22.—Voltage produced by light.

2. It collects the electrons emitted by the copper oxide.

An externally connected wire completes the electron path, the same as in the reflector-type cell. The photocell's voltage is used as needed by connecting the external wires to some other device, which amplifies (enlarges) it to a usable level.

The power capacity of a photocell is very small. However, it reacts to light-intensity variations in an extremely short time. This characteristic makes the photocell very useful in detecting or accurately controlling a great number of operations. For instance, the photoelectric cell, or some form of the photoelectric principle, is used in television cameras, automatic manufacturing process controls, door openers, burglar alarms, and so forth.

Voltage Produced by Chemical Action

Voltage may be produced chemically when certain substances are exposed to chemical action.

If two dissimilar substances (usually metals or metallic materials) are immersed in a solution that produces a greater chemical action on one substance than on the other, a difference of potential will exist between the two. If a conductor is then connected between them, electrons will flow through the conductor to equalize the charge. This arrangement is called a primary cell. The two metallic pieces are called electrodes and the solution is called the electrolyte. The voltaic cell illustrated in figure 1-23 is a simple example of a primary cell. The difference of potential results from the fact that material from one or both of the electrodes goes into solution in the electrolyte, and in the process, ions form in the vicinity of the electrodes. Due to the electric field associated with the charged ions, the electrodes acquire charges.

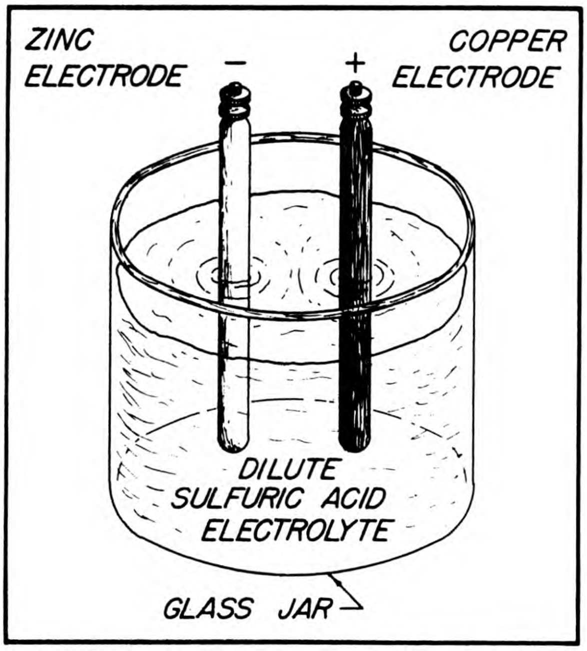

Figure 1-23.—Voltaic cell.

The amount of difference in potential between the electrodes depends principally on the metals used. The type of electrolyte and the size of the cell have little or no effect on the potential difference produced.

There are two types of primary cells, the wet cell and the dry cell. In a wet cell the electrolyte is a liquid. A cell with a liquid electrolyte must remain in an upright position and is not readily transportable. An automotive battery is an example of this type of cell. The dry cell, much more commonly used than the wet cell, is not actually dry, but contains an electrolyte mixed with other materials to form a paste. Flashlights and portable radios are commonly powered by dry cells.

Batteries are formed when several cells are connected together to increase electrical output.

Voltage Produced by Magnetism

Magnets or magnetic devices are used for thousands of different jobs. One of the most useful and widely employed applications of magnets is in the production of vast quantities of electric power from mechanical sources. The mechanical power may be provided by a number of different sources, such as gasoline or diesel engines, and water or steam turbines. However, the final conversion of these source energies to electricity is done by generators employing the principle of electromagnetic induction. These generators, of many types and sizes, are discussed in other modules in this series. The important subject to be discussed here is the fundamental operating principle of ALL such electromagnetic-induction generators.

To begin with, there are three fundamental conditions which must exist before a voltage can be produced by magnetism.

1. There must be a CONDUCTOR in which the voltage will be produced.

2. There must be a MAGNETIC FIELD in the conductor's vicinity.

3. There must be relative motion between the field and conductor. The conductor must be moved so as to cut across the magnetic lines of force, or the field must be moved so that the lines of force are cut by the conductor.

In accordance with these conditions, when a conductor or conductors MOVE ACROSS a magnetic field so as to cut the lines of force, electrons WITHIN THE CONDUCTOR are propelled in one direction or another. Thus, an electric force, or voltage, is created.

In figure 1-24, note the presence of the three conditions needed for creating an induced voltage.

1. A magnetic field exists between the poles of the C-shaped magnet.

2. There is a conductor (copper wire).

3. There is a relative motion. The wire is moved back and forth ACROSS the magnetic field.

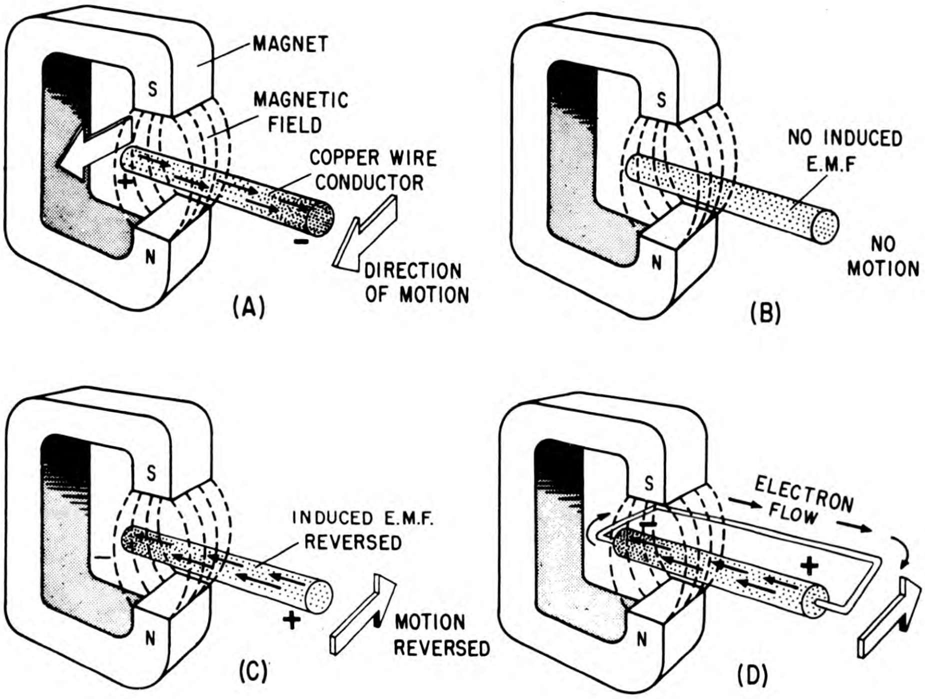

Figure 1-24.—Voltage produced by magnetism.

In figure 1-24(A), the conductor is moving TOWARD the front of the page and the electrons move from left to right. The movement of the electrons occurs because of the magnetically induced emf acting on the electrons in the copper. The right-hand end becomes negative, and the left-hand end positive. The conductor is stopped at (B), motion is eliminated (one of the three required conditions), and there is no longer an induced emf. Consequently, there is no longer any difference in potential between the two ends of the wire. The conductor at (C) is moving away from the front of the page. An induced emf is again created. However, note carefully that the REVERSAL OF MOTION has caused a REVERSAL OF DIRECTION in the induced emf.

If a path for electron flow is provided between the ends of the conductor, electrons will leave the negative end and flow to the positive end. This condition is shown in part (D). Electron flow will continue as long as the emf exists. In studying figure 1-24, it should be noted that the induced emf could also have been created by holding the conductor stationary and moving the magnetic field back and forth.

The more complex aspects of power generation by use of mechanical motion and magnetism are discussed later in this series, under the heading "Generators and Motors".

Q40. Name the six methods of producing a voltage.

Q41. The piezoelectric effect is an example of a voltage being produced by what method?

Q42. A thermocouple is a device that produces voltage by what method?

Q43. A battery uses what method to produce a voltage?

Q44. A generator uses what method to produce a voltage?

ELECTRIC CURRENT

It has been proven that electrons (negative charges) move through a conductor in response to an electric field. ELECTRON CURRENT FLOW will be used throughout this explanation. Electron current is defined as the directed flow of electrons. The direction of electron movement is from a region of negative potential to a region of positive potential. Therefore, electric current can be said to flow from negative to positive. The direction of current flow in a material is determined by the polarity of the applied voltage. NOTE: In some electrical/electronic communities the direction of current flow is recognized as being from positive to negative.

Q45. According to electron theory, an electric current flows from what potential to what potential?

Random Drift

All materials are composed of atoms, each of which is capable of being ionized. If some form of energy, such as heat, is applied to a material, some electrons acquire sufficient energy to move to a higher energy level. As a result, some electrons are freed from their parent atoms, which then becomes ions. Other forms of energy, particularly light or an electric field, will cause ionization to occur.

The number of free electrons resulting from ionization is dependent upon the quanitity of energy applied to a material, as well as the atomic structure of the material. At room temperature some materials, classified as conductors, have an abundance of free electrons. Under a similar condition, materials classified as insulators have relatively few free electrons.

In a study of electric current, conductors are of major concern. Conductors are made up of atoms that contain loosely bound electrons in their outer orbits. Due to the effects of increased energy, these outermost electrons frequently break away from their atoms and freely drift throughout the material. The free electrons, also called mobile electrons, take a path that is not predictable and drift about the material in a haphazard manner. Consequently, such a movement is termed RANDOM DRIFT.

It is important to emphasize that the random drift of electrons occurs in all materials. The degree of random drift is greater in a conductor than in an insulator.

Directed Drift

Associated with every charged body there is an electrostatic field. Bodies that are charged alike repel one another and bodies with unlike charges attract each other. An electron will be affected by an electrostatic field in exactly the same manner as any negatively charged body. It is repelled by a negative charge and attracted by a positive charge. If a conductor has a difference in potential impressed across it, as shown in figure 1-25, a direction is imparted to the random drift. This causes the mobile electrons to be repelled away from the negative terminal and attracted toward the positive terminal. This constitutes a general migration of electrons from one end of the conductor to the other. The directed migration of mobile electrons due to the potential difference is called DIRECTED DRIFT.

The directed movement of the electrons occurs at a relatively low VELOCITY (rate of motion in a particular direction). The effect of this directed movement, however, is felt almost instantaneously, as explained by the use of figure 1-26. As a difference in potential is impressed across the conductor, the positive terminal of the battery attracts electrons from point A. Point A now has a deficiency of electrons. As a result, electrons are attracted from point B to point A. Point B has now developed an electron deficiency, therefore, it will attract electrons. This same effect occurs throughout the conductor and repeats itself from points D to C. At the same instant the positive battery terminal attracted electrons from point A, the negative terminal repelled electrons toward point D. These electrons are attracted to point D as it gives up electrons to

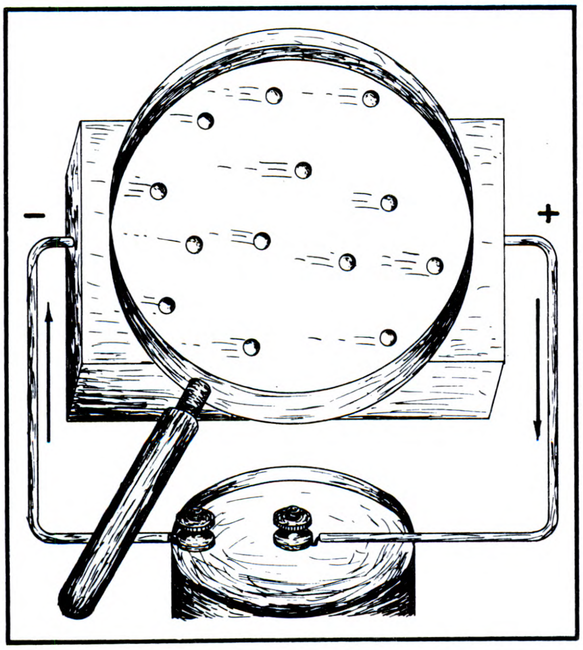

Figure 1-25.—Directed drift.

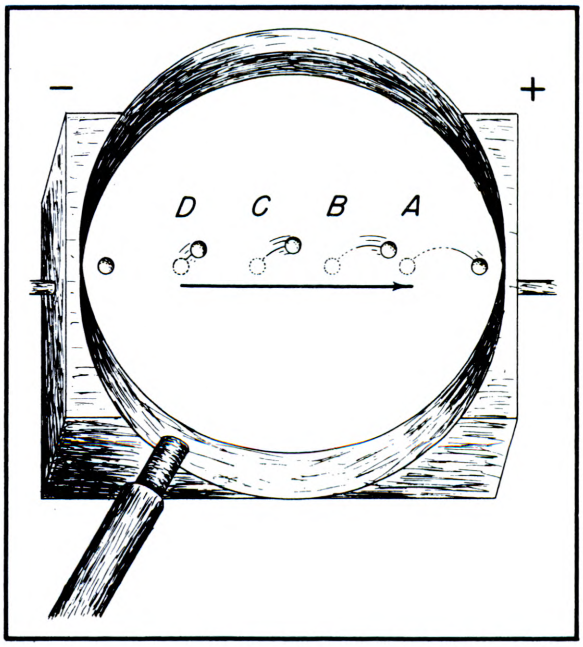

Figure 1-26.—Effect of directed drift.

A40. **Friction, pressure, heat, light, chemical action, and magnetism**

A41. **Pressure**

A42. **Heat**

A43. **Chemical**

A44. **Magnetic**

A45. **Electron theory assumes that electron flow is from negative to positive**

point C. This process is continuous for as long as a difference of potential exists across the conductor. Though an individual electron moves quite slowly through the conductor, the effect of a directed drift occurs almost instantaneously. As an electron moves into the conductor at point D, an electron is leaving at point A. This action takes place at approximately the speed of light. (186,000 miles Per Second.)

Q46. **The effects of directed drift take place at what rate of speed?**

Magnitude of Current Flow

Electric current has been defined as the directed movement of electrons. Directed drift, therefore, is current and the terms can be used interchangeably. The expression directed drift is particularly helpful in differentiating between the random and directed motion of electrons. However, CURRENT FLOW is the terminology most commonly used in indicating a directed movement of electrons.

The magnitude of current flow is directly related to the amount of energy that passes through a conductor as a result of the drift action. An increase in the number of energy carriers (the mobile electrons) or an increase in the energy of the existing mobile electrons would provide an increase in current flow. When an electric potential is impressed across a conductor, there is an increase in the velocity of the mobile electrons causing an increase in the energy of the carriers. There is also the generation of an increased number of electrons providing added carriers of energy. The additional number of free electrons is relatively small, hence the magnitude of current flow is primarily dependent on the velocity of the existing mobile electrons.

The magnitude of current flow is affected by the difference of potential in the following manner. Initially, mobile electrons are given additional energy because of the repelling and attracting electrostatic field. If the potential difference is increased, the electric field will be stronger, the amount of energy imparted to a mobile electron will be greater, and the current will be increased. If the potential difference is decreased, the strength of the field is reduced, the energy supplied to the electron is diminished, and the current is decreased.

Q47. **What is the relationship of current to voltage in a circuit?**

Measurement of Current

The magnitude of current is measured in AMPERES. A current of one ampere is said to flow when one coulomb of charge passes a point in one second. Remember, one coulomb is equal to the charge of 6.28×10^{18} electrons.

Frequently, the ampere is much too large a unit for measuring current. Therefore, the MILLIAMPERE (mA), one-thousandth of an ampere, or the MICROAMPERE (μA), one-millionth of an ampere, is used. The device used to measure current is called an AMMETER and will be discussed in detail in a later module.

Q48. Convert 350mA to amperes.

ELECTRICAL RESISTANCE

It is known that the directed movement of electrons constitutes a current flow. It is also known that the electrons do not move freely through a conductor's crystalline structure. Some materials offer little opposition to current flow, while others greatly oppose current flow. This opposition to current flow is known as RESISTANCE (R), and the unit of measure is the OHM. The standard of measure for one ohm is the resistance provided at zero degrees Celsius by a column of mercury having a cross-sectional area of one square millimeter and a length of 106.3 centimeters. A conductor has one ohm of resistance when an applied potential of one volt produces a current of one ampere. The symbol used to represent the ohm is the Greek letter omega (Ω).

Resistance, although an electrical property, is determined by the physical structure of a material. The resistance of a material is governed by many of the same factors that control current flow. Therefore, in a subsequent discussion, the factors that affect current flow will be used to assist in the explanation of the factors affecting resistance.

Q49. What is the symbol for ohm?

Factors That Affect Resistance

The magnitude of resistance is determined in part by the "number of free electrons" available within the material. Since a decrease in the number of free electrons will decrease the current flow, it can be said that the opposition to current flow (resistance) is greater in a material with fewer free electrons. Thus, the resistance of a material is determined by the number of free electrons available in a material.

A knowledge of the conditions that limit current flow and, therefore, affect resistance can now be used to consider how the type of material, physical dimensions, and temperature will affect the resistance of a conductor.

TYPE OF MATERIAL.—Depending upon their atomic structure, different materials will have different quantities of free electrons. Therefore, the various conductors used in electrical applications have different values of resistance.

Consider a simple metallic substance. Most metals are crystalline in structure and consist of atoms that are tightly bound in the lattice network. The atoms of such elements are so close together that the electrons in the outer shell of the atom are associated with one atom as much as with its neighbor. (See fig. 1-27A.) As a result, the force of attachment of an outer electron with an individual atom is practically zero. Depending on the metal, at least one

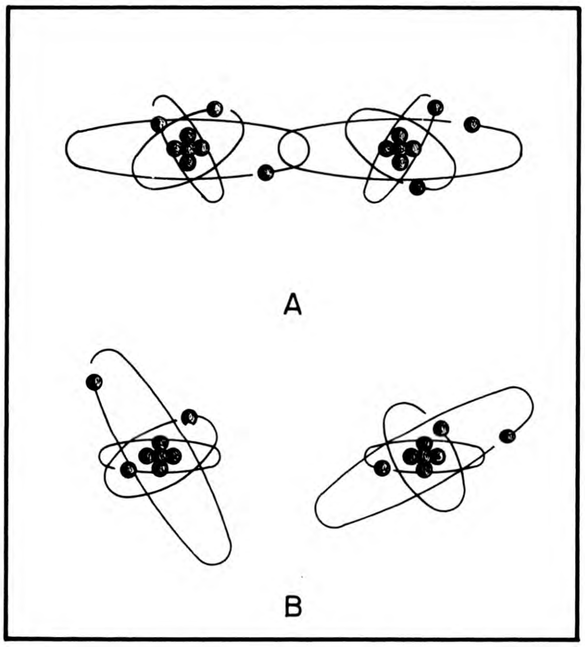

Figure 1-27.—Atomic spacing in conductors.

A46. The speed of light (186,000 miles per second, 300,000,000 meters per second)

A47. Current increases as voltage increases

A48. 0.35 amperes

A49. Ω

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electron, sometimes two, and, in a few cases, three electrons per atom exist in this state. In such a case, a relatively small amount of additional electron energy would free the outer electrons from the attraction of the nucleus. At normal room temperature materials of this type have many free electrons and are good conductors. Good conductors will have a low resistance.

If the atoms of a material are farther apart, as illustrated in figure 1-27(B), the electrons in the outer shells will not be equally attached to several atoms as they orbit the nucleus. They will be attracted by the nucleus of the parent atom only. Therefore, a greater amount of energy is required to free any of these electrons. Materials of this type are poor conductors and therefore have a high resistance.

Silver, gold, and aluminum are good conductors. Therefore, materials composed of their atoms would have a low resistance.

The element copper is the conductor most widely used throughout electrical applications. Silver has a lower resistance than copper but its cost limits usage to circuits where a high conductivity is demanded.

Aluminum, which is considerably lighter than copper, is used as a conductor when weight is a major factor.

Q50. When would silver be used as a conductor in preference to copper?

EFFECT OF CROSS-SECTIONAL AREA.—Cross-sectional area greatly affects the magnitude of resistance. If the cross-sectional area of a conductor is increased, a greater quantity of electrons are available for movement through the conductor. Therefore, a larger current will flow for a given amount of applied voltage. An increase in current indicates that when the cross-sectional area of a conductor is increased, the resistance must have decreased. If the cross-sectional area of a conductor is decreased, the number of available electrons decreases and, for a given applied voltage, the current through the conductor decreases. A decrease in current flow indicates that when the cross-sectional area of a conductor is decreased, the resistance must have increased. Thus, the RESISTANCE OF A CONDUCTOR IS INVERSELY PROPORTIONAL TO ITS CROSS-SECTIONAL AREA.

The diameter of conductors used in electronics is often only a fraction of an inch, therefore, the diameter is expressed in mils (thousandths of an inch). It is also standard practice to assign the unit circular mil to the cross-sectional area of the conductor. The circular mil is found by squaring the diameter, when the diameter is expressed in mils. Thus, if the diameter is 35 mils (0.035 inch), the circular mil area is equal to $(35)^2$ or 1225 circular mils. A comparison between a square mil and a circular mil is illustrated in figure 1-28.

EFFECT OF CONDUCTOR LENGTH.—The length of a conductor is also a factor which determines the resistance of a conductor. If the length of a conductor is increased, the amount of energy given up increases. As free electrons move from atom to atom some energy is given off as heat. The longer a conductor is, the more energy is lost to heat. The additional energy loss subtracts from the energy being transferred through the conductor, resulting in a decrease in current flow for a given applied voltage. A decrease in current flow indicates an increase in resistance, since voltage was held constant. Therefore, if the length of a conductor is increased, the resistance increases. THE RESISTANCE OF A CONDUCTOR IS DIRECTLY PROPORTIONAL TO ITS LENGTH.

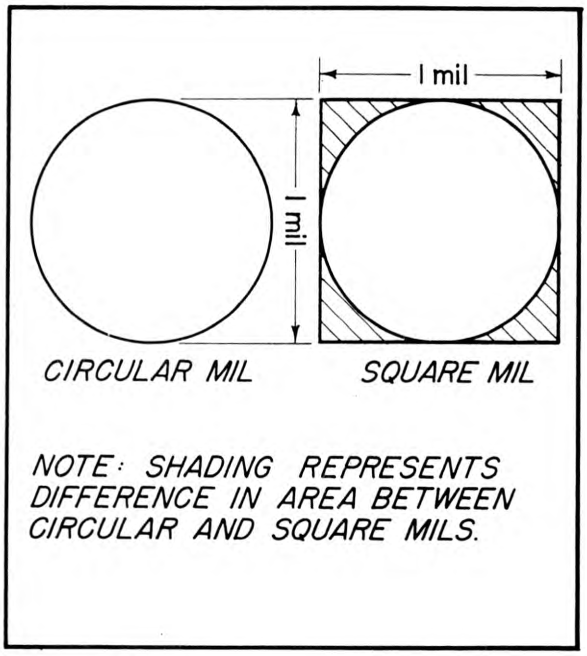

1 mil
1 mil
CIRCULAR MIL
SQUARE MIL
NOTE: SHADING REPRESENTS DIFFERENCE IN AREA BETWEEN CIRCULAR AND SQUARE MILS.

Figure 1-28.—Square and circular mil.

Q51. Which wire has the least resistance? Wire A - copper, 1000 circular mils, 6 inches long. Wire B - copper, 2000 circular mils, 11 inches long

EFFECT OF TEMPERATURE.—Temperature changes affect the resistance of materials in different ways. In some materials an increase in temperature causes an increase in resistance, whereas in others, an increase in temperature causes a decrease in resistance. The amount of change of resistance per unit change in temperature is known as the TEMPERATURE COEFFICIENT. If for an increase in temperature the resistance of a material increases, it is said to have a POSITIVE TEMPERATURE COEFFICIENT. A material whose resistance decreases with an increase in temperature has a NEGATIVE TEMPERATURE COEFFICIENT. Most conductors used in electronic applications have a positive temperature coefficient. However, carbon, a frequently used material, is a substance having a negative temperature coefficient. Several materials, such as the alloys constantan and manganin, are considered to have a ZERO TEMPERATURE COEFFICIENT because their resistance remains relatively constant for changes in temperature.

Q52. Which temperature coefficient indicates a material whose resistance increases as temperature increases?

Q53. What term describes a material whose resistance remains relatively constant with changes in temperature?

CONDUCTANCE

Electricity is a study that is frequently explained in terms of opposites. The term that is the opposite of resistance is CONDUCTANCE. Conductance is the ability of a material to pass electrons. The factors that affect the magnitude of resistance are exactly the same for conductance, but they affect conductance in the opposite manner. Therefore, conductance is directly proportional to area, and inversely proportional to the length of the material. The temperature of the material is definitely a factor, but assuming a constant temperature, the conductance of a material can be calculated.

The unit of conductance is the MHO, which is ohm spelled backwards. Another term for mho is SIEMENS. Whereas the symbol used to represent resistance (R) is the Greek letter omega (Ω), the symbol used to represent conductance (G) is (S). The relationship that exists between resistance (R) and conductance (G) is a reciprocal one. A reciprocal of a number is one divided by that number. In terms of resistance and conductance:

$$R = \frac{1}{G}$$

$$G = \frac{1}{R}$$

A50. **When the need for conductivity is great enough to justify the additional expense**

A51. Wire B

A52. Positive

A53. **Zero temperature coefficient**

Q54. What is the unit of conductance and what other term is sometimes used?

Q55. What is the relationship between conductance and resistance?

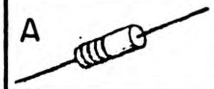
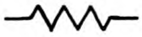
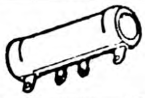
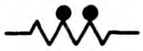
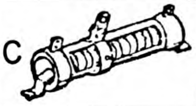
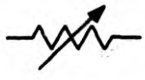
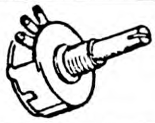
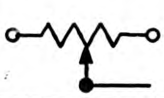
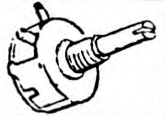
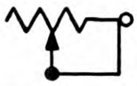
TYPICAL RESISTOR	TYPE	SYMBOL
A 	FIXED CARBON	
B 	FIXED WIREWOUND (TAPPED)	
C 	ADJUSTABLE WIREWOUND	
D 	POTENTIOMETER	
E 	RHEOSTAT	

Figure 1-29.—Types of resistors.

ELECTRICAL RESISTORS

Resistance is a property of every electrical component. At times, its effects will be undesirable. However, resistance is used in many varied ways. RESISTORS are components manufactured to possess specific values of resistance. They are manufactured in many types and sizes. When drawn using its schematic representation, a resistor is shown as a series of jagged lines, as illustrated in figure 1-29.

Q56. What is schematic symbol for a resistor?

Composition of Resistors

One of the most common types of resistors is the molded composition, usually referred to as the carbon resistor. These resistors are manufactured in a variety of sizes and shapes. The chemical composition of the resistor determines its ohmic value and is accurately controlled by the manufacturer in the development process. They are made in ohmic values that range from one ohm to millions of ohms. The physical size of the resistor is related to its wattage rating, which is the ability of the resistor to dissipate heat caused by the resistance.

Carbon resistors, as you might suspect, have as their principal ingredient the element carbon. In the manufacture of carbon resistors, fillers or binders are added to the carbon to obtain various resistor values. Examples of these fillers are clay, bakelite, rubber, and talc. These fillers are doping agents and cause the overall conduction characteristics to change.

Carbon resistors are the most common resistors found because they are easy to manufacture, inexpensive, and have a tolerance that is adequate for most electrical and electronic applications. Their prime disadvantage is that they have a tendency to change value as they age. One other disadvantage of carbon resistors is their limited power handling capacity.

The disadvantage of carbon resistors can be overcome by the use of WIREWOUND resistors (fig. 1-29 B and C). Wirewound resistors have very accurate values and possess a higher current handling capability than carbon resistors. The material that is frequently used to manufacture wirewound resistors is German silver which is composed of copper, nickel, and zinc. The qualities and quantities of these elements present in the wire determine the resistivity of the wire. (The resistivity of the wire is the measure or ability of the wire to resist current. Usually the percent of nickel in the wire determines the resistivity.) One disadvantage of the wirewound resistor is that it takes a large amount of wire to manufacture a resistor of high ohmic value, thereby increasing the cost. A variation of the wirewound resistor provides an exposed surface to the resistance wire on one side. An adjustable tap is attached to this side. Such resistors, sometimes with two or more adjustable taps, are used as voltage dividers in power supplies and other applications where a specific voltage is desired to be "tapped" off.

Q57. What does the wattage rating of a resistor indicate?

Q58. What are the two disadvantages of carbon type resistors?

Q59. What type resistor should be used to overcome the disadvantages of the carbon resistor?

Fixed and Variable Resistors

There are two kinds of resistors, FIXED and VARIABLE. The fixed resistor will have one value and will never change (other than through temperature, age, etc.). The resistors shown in A and B of figure 1-29 are classed as fixed resistors. The tapped resistor illustrated in B has several fixed taps and makes more than one resistance value available. The sliding contact resistor shown in C has an adjustable collar that can be moved to tap off any resistance within the ohmic value range of the resistor.

There are two types of variable resistors, one called a POTENTIOMETER and the other a RHEOSTAT (see views D and E of Fig. 1-29). An example of the potentiometer is the volume control on your radio, and an example of the rheostat is the dimmer control for the dash lights in an automobile. There is a slight difference between them. Rheostats usually have two connections, one fixed and the other moveable. Any variable resistor can properly be called a rheostat. The potentiometer always has three connections, two fixed and one moveable. Generally, the rheostat has a limited range of values and a high current-handling capability. The potentiometer has a wide range of values, but it usually has a limited current-handling capability. Potentiometers are always connected as voltage dividers. (Voltage dividers are discussed in Topic 3.)

Q60. Describe the differences between the rheostat connections and those of the potentiometer.

Q61. Which type of variable resistor should you select for controlling a large amount of current?

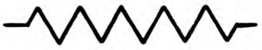
Wattage Rating

When a current is passed through a resistor, heat is developed within the resistor. The resistor must be capable of dissipating this heat into the surrounding air; otherwise, the temperature of the resistor rises causing a change in resistance, or possibly causing the resistor to burn out.

The ability of the resistor to dissipate heat depends upon the design of the resistor itself. This ability to dissipate heat depends on the

A54. **The mho (υ), siemans**

A55. **They are reciprocals of each other**

A56. 

A57. **Its ability to dissipate heat**

A58. **1. Change value with age**
2. Limited power capacity

A59. **The wirewound resistor**

A60. **The rheostat may have two connections, one fixed and one moveable; the potentiometer always has three connections, one moveable and two fixed**

A61. **The rheostat**

---

amount of surface area which is exposed to the air. A resistor designed to dissipate a large amount of heat must therefore have a large physical size. The heat dissipating capability of a resistor is measured in WATTS (this unit will be explained later in topic 3). Some of the more common wattage ratings of carbon resistors are: one-eighth watt, one-fourth watt, one-half watt, one watt, and two watts. In some of the newer state-of-the-art circuits of today, much smaller wattage resistors are used. Generally, the type that you will be able to physically work with are of the values given. The higher the wattage rating of the resistor the larger is the physical size. Resistors that dissipate very large amounts of power (watts) are usually wirewound resistors. Wirewound resistors with wattage ratings up to 50 watts are not uncommon. Figure 1-30 shows some resistors which have different wattage ratings. Notice the relative sizes of the resistors.

Standard Color Code System

In the standard color code system, four bands are painted on the resistor, as shown in figure 1-31.

The color of the first band indicates the value of the first significant digit. The color of the second band indicates the value of the second significant digit. The third color band represents a decimal multiplier by which the

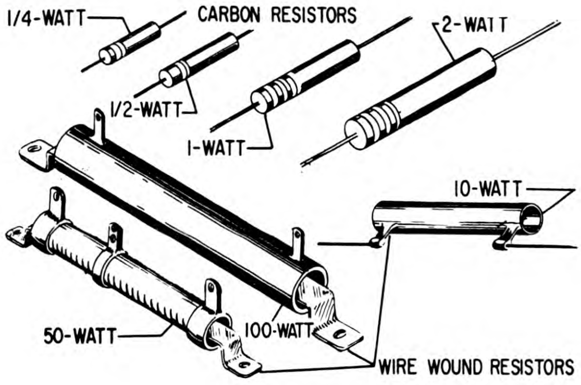


Figure 1-30.—Resistors of different wattage ratings.

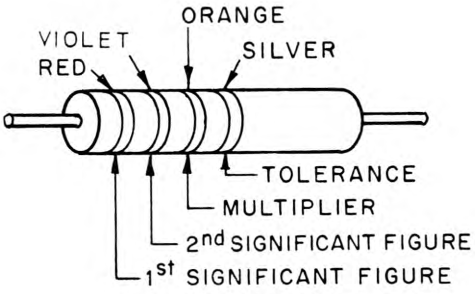


Figure 1-31.—Resistor color codes.

first two digits must be multiplied to obtain the resistance value of the resistor. The colors for the bands and their corresponding values are shown in Table 1-1.

Use the example colors shown in figure 1-31. Since red is the color of the first band, the first significant digit is 2. The second band is violet, therefore the second significant digit is 7. The third band is orange, which indicates that the number formed as a result of reading the first two bands is multiplied by 1000. In this case 27 × 1000 = 27,000 ohms. The last band on the resistor indicates the tolerance; that is, the manufacturer's allowable deviation from the numerical value given on the resistor. In this instance its color is silver, and the tolerance is 10 percent plus or minus of the value of the resistor. The allowed limit of variation in ohmic value of this particular resistor is 24,300 to 29,700 ohms.

When measuring resistors you will find situations in which the quantities to be measured may be extremely large, and the resulting number using the basic unit, the ohm, may prove too cumbersome. Therefore, a metric system prefix is usually attached to the basic unit of measurement to provide a more manageable unit. Two of the most commonly used prefixes are kilo and mega. Kilo is the prefix used to represent thousand and is abbreviated k. Mega is the prefix used to represent million and is abbreviated M.

Table 1-1.—Standard Color Code for Resistors

COLOR	SIGNIFICANT FIGURE	DECIMAL MULTIPLIER	RESISTANCE TOLERANCE	RELIABILITY LEVEL PER 1000 HRS.
BLACK	0	1	PERCENT	
BROWN	1	10	1	1%
RED	2	100	2	.1%
ORANGE	3	1 000	3	.01%
YELLOW	4	10,000	...	.001%
GREEN	5	100,000		
BLUE	6	1,000,000		
VIOLET	7	10,000,000	...	
GRAY	8	100,000,000	...	
WHITE	9	1,000,000,000	...	
GOLD	...	.1	5	
SILVER	...	.01	10	
NO COLOR	...		20	

In the example given above, the 27,000-ohm resistor could have been written as 27 kilohms or 27 kΩ. Other examples are: 1,000 ohms = 1 kΩ; 10,000 ohms = 10 KΩ; 100,000 ohms = 100 kΩ. Likewise, 1,000,000 ohms is written as 1 megohm or 1 MΩ and 10,000,000 ohms = 10 MΩ.

Q62. A carbon resistor has a resistance of 50 ohms, and a tolerance of 5 percent. What are the colors of bands one, two, three, and four, respectively?

SIMPLIFYING THE COLOR CODE.—Resistors are the most common components used in electronics. The technician must identify, select, check, remove, and replace resistors. Resistors and resistor circuits are usually the easiest branches of electronics to understand.

The resistor color code sometimes presents problems to a technician. It really should not, because once the resistor color code is learned, you should remember it for the rest of your life.

Black, brown, red, orange, yellow, green, blue, violet, gray, white—this is the order of colors you should know automatically. There is a memory aid that will help you remember the code in its proper order. Each word starts with the first letter of the colors. If you match it up with the color code, you will not forget the code.

Bad Boys Run Over Yellow Gardenias Behind Victory Garden Walls.

or

Black — Bad
Brown — Boys
Red — Run
Orange — Over
Yellow — Yellow
Green — Gardenias
Blue — Behind
Violet — Victory
Gray — Garden
White — Walls

A62. The bands are green, black, black, and gold

There are many other memory aid sentences that you might want to ask about from experienced technicians. You might find one of the other sentences easier to remember.

There is still a good chance that you will make a mistake on a resistor's color band. Most technicians do at one time or another. If you make a mistake on the first two significant colors, it usually is not too serious. If you make a miscue on the third band, you are in trouble, because the value is going to be at least 10 times too high or too low. Some important points to remember about the third band are:

When the third band is. . . .

Black, the resistor must be less than 100 ohms.

Red, the resistor must be in hundreds of ohms.

Orange, the resistor must be in thousands of ohms.

Yellow, the resistor must be in hundreds of thousands of ohms.

Green, the resistor must be in megohms.

Blue, the resistor must be in tens of megohms or more.

Red, orange, and yellow are the most common colors for the third band. If this is kept in mind the selection of resistors from a parts bin, a lot of trouble can be avoided.

The fourth band, which is the tolerance band, usually does not present too much of a problem. If there is no fourth band, it means that the resistor has a 20-percent tolerance, a silver fourth band has a 10-percent tolerance, and a gold fourth band has a 5-percent tolerance. In some cases, the third band will be silver or gold. It then becomes a multiplier, and you multiply the first two bands by 0.01 if it is silver, and 0.1 if it is gold. Resistors that conform to military specifications have an additional fifth band. The fifth band indicates the reliability level per 1,000 hours as follows:

Fifth band color	Level
Brown	1.0%
Red	0.1%
Orange	0.01%
Yellow	0.001%

In applying the reliability level table for a resistor color coded brown, the chance of failure will not exceed 1 percent for every 1,000 hours of operation of that resistor. In equipment such as the Navy's complex computers this is very significant. In a piece of equipment containing 10,000 orange fifth-band resistors, it means that no more than one resistor will fail during 1,000 hours of operation. This is very good reliability. More information on resistors can be found in NEETS Module 19.

Q63. A carbon resistor has the following color bands: The first band is yellow, followed by violet, yellow, and silver. What is the ohmic value of the resistor?

Q64. The same resistor mentioned in question 63 has a yellow fifth band. What does this signify?

Q65. A resistor is handed to you for identification with the following color code: first band is blue, followed by gray, green, gold, and brown. What is the resistor's value?

Some resistors, both wirewound and composition, will not use the resistor color code. These resistors will have the ohmic value and tolerance imprinted on the resistor itself.

SUMMARY OF TOPIC 1

With the completion of this topic you now have gained the necessary information which is the foundation for the further study of electricity. The following is a summary of the important parts in the topic.

In describing the composition of matter the following terms are important for you to remember:

MATTER is defined as anything that occupies space and has weight.

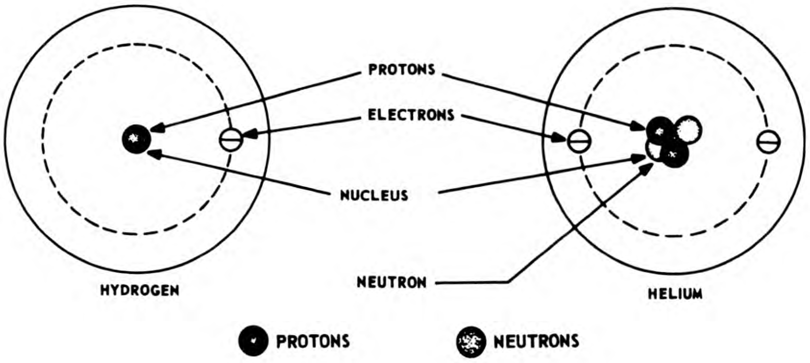
AN ELEMENT is a substance which cannot be reduced to a simpler substance by chemical means.

A COMPOUND is a chemical combination of elements which can be separated by chemical means, but not by physical means. It is created by chemically combining two or more elements.

A MIXTURE is a combination of elements or compounds that can be separated by physical means.

A MOLECULE is the chemical combination of two or more atoms. In a compound, the molecule is the smallest particle that has all the characteristics of the compound.

AN ATOM is the smallest particle of an element that retains the characteristics of that element. An atom is made up of electrons, protons, and neutrons. The number and arrangement of these subatomic particles determines the kind of element.



AN ELECTRON is considered to be a negative charge of electricity.

A PROTON is considered to be a positive charge of electricity.

A NEUTRON is a neutral particle in that it has no electrical charge.

A63. 470,000 ohms (470 kilohms)

A64. The resistor's chance of failure is 0.001 percent for 1000 hours of operation

A65. 6,800,000 ohms (6.8 megohms), with 5% tolerance, and a 1% reliability level

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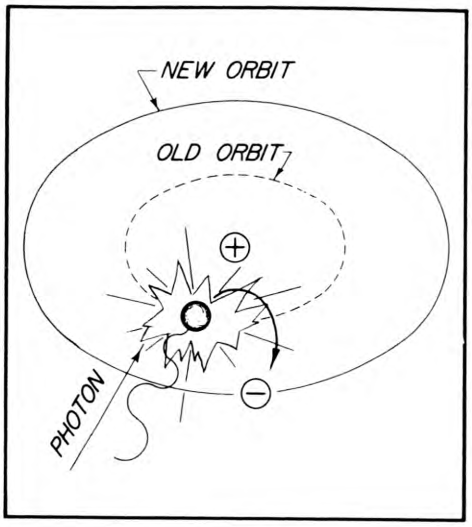
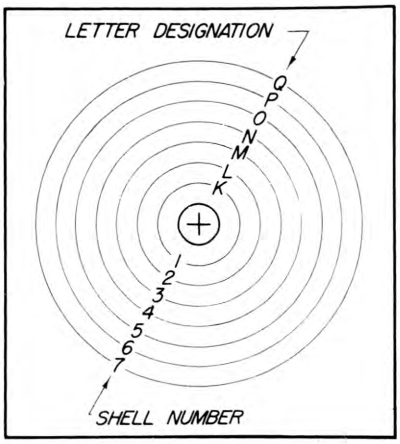
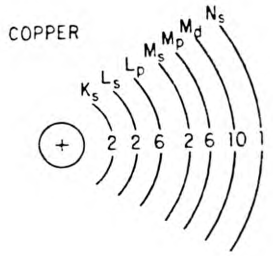


ENERGY in an electron is of two types–kinetic (energy of motion) and potential (energy of position).

ENERGY LEVELS of the electron exist because the electron has mass and motion. The motion gives it kinetic energy and its position gives it potential energy. Energy balance keeps the electron in orbit and should it gain energy it will assume an orbit further from the center of the atom. It will remain at that level for only a fraction of a second before it radiates the excess energy and goes back to a lower orbit.

SHELLS AND SUBSHELLS of electrons are the orbits of the electrons in the atom. Each shell contains a maximum of 2 times its number squared electrons. Shells are lettered K through Q, starting with K, which is the closest to the nucleus. The shell can be split into 4 subshells labeled s, p, d, and f, which can contain 2, 6, 10, and 14 electrons, respectively.



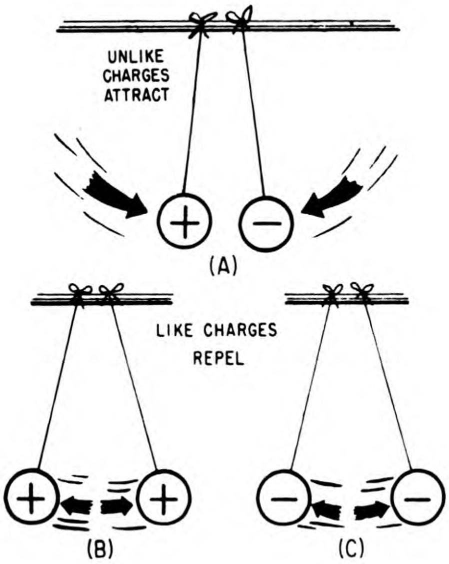


VALENCE OF AN ATOM is determined by the number of electrons in the outermost shell. The shell is referred to as the valence shell, and the electrons within it are valence electrons. An atom with few valence electrons requires little energy to free the valence electrons.

IONIZATION refers to the electrons contained in an atom. An atom with a positive charge has lost some of its electrons, and is called a positive ion. A negatively charged atom is a negative ion.

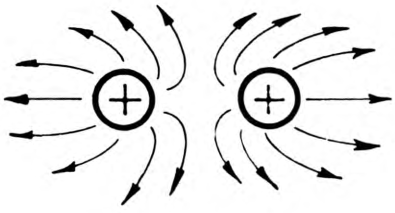
CONDUCTORS, SEMICONDUCTORS, AND INSULATORS are categorized as such by the number of valence electrons in their atoms. The conductor normally has 3 or less valence electrons and offers little opposition to the flow of electrons (electric current). The insulator contains 5 or more valence electrons and offers high opposition to electron flow. The semiconductor usually has four valence electrons of conductivity and are in the midrange. The best conductors in order of conductance are silver, copper, gold, and aluminum.

CHARGED BODIES affect each other as follows: When two bodies having unequal charges are brought close to each other, they will tend to attract each other in an attempt to equalize their respective charges. When two bodies, both having either positive or negative charges, are brought close together, they tend to repell each other as no equalization can occur. When the charge on one body is high enough with respect to the charge on an adjacent body, an equalizing current will flow between the bodies regardless of the conductivity of the material containing the bodies.



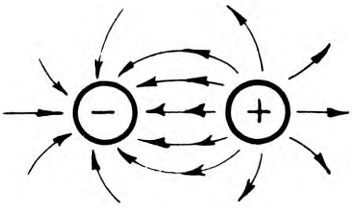
A NEUTRAL BODY may be attracted to either a positively or negatively charged body due to the relative difference in their respective charges.

CHARGED BODIES will attract or repell each other with a force that is directly proportional to the product of their individual charges and inversely proportional to the square of the distance between the bodies.



(A)

ELECTROSTATIC LINES of force are a graphic representation of the field around a charged body. These lines are imaginary. Lines from a positively charged body are indicated as flowing out from the body, while lines from a negatively charged body are indicated as flowing into the body.



(B)

MAGNETISM is that property of a material which enables it to attract pieces of iron. A material with this property is called a magnet. Any material that is attracted to a magnet can be made into a magnet itself.

FERROMAGNETIC MATERIALS are materials that are easy to magnetize, e.g., iron, steel, and cobalt.

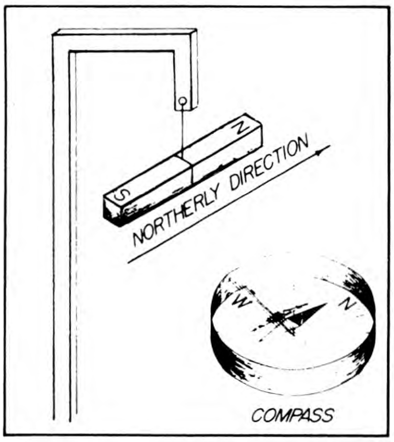
NATURAL MAGNETS, called magnitite, lodestones, or leading stones, were the first magnets to be studied. Most magnets in practical use are artificial or man-made magnets, and are made either by electrical means or by stroking a magnetic material with a magnet.

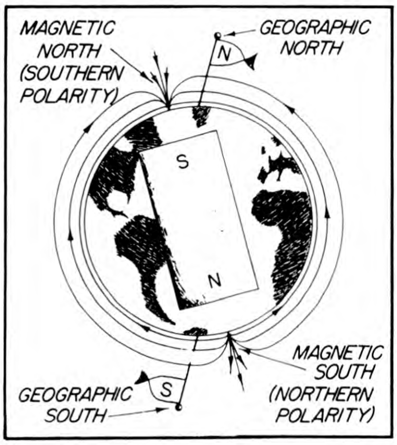
RELUCTANCE is defined as the opposition of a material to being magnetized.

PERMEABILITY is defined as the ease with which a material accepts magnetism. A material which is easy to magnetize does not hold its magnetism very long, and vice versa.

RETENTIVETY is defined as the ability of a material to retain magnetism.

A MAGNETIC POLE is located at each end of a magnet. The majority of the magnetic force is concentrated at these poles and is approximately equal at both poles.

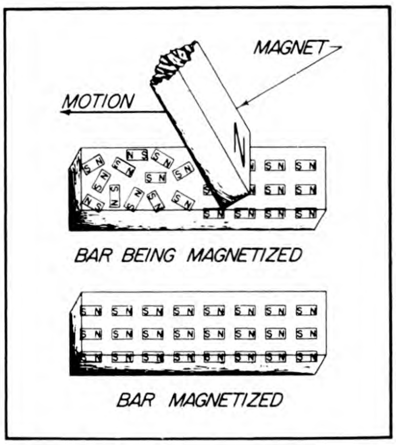

S
N
NORTHERLY DIRECTION
N
W
COMPASS


MAGNETIC NORTH (SOUTHERN POLARITY)
GEOGRAPHIC NORTH
N
S
N
MAGNETIC SOUTH (NORTHERN POLARITY)
GEOGRAPHIC SOUTH
S

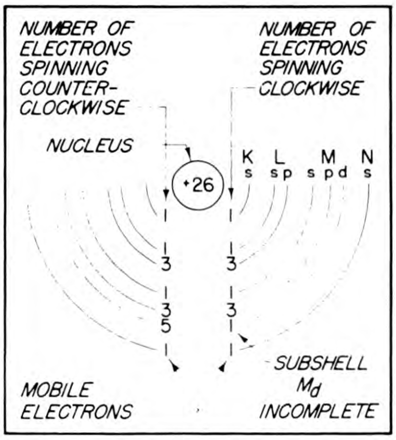
THE NORTH POLE, or north seeking pole, of a magnet freely suspended on a string always points toward the north geographical pole.

THE LIKE POLES of magnets repel each other, while the unlike poles attract each other.

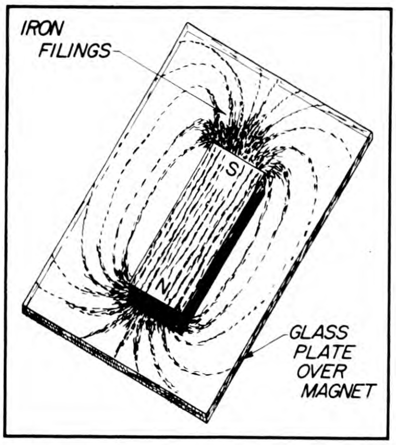
WEBER'S THEORY OF MAGNETISM assumes that all magnetic material is made up of magnetic molecules which, if lined up in north to south pole order, will be a magnet. If not lined up, the magnetic fields about the molecules will neutralize each other and no magnetic effect will be noted.


MAGNET
MOTION
N
S N
BAR BEING MAGNETIZED
S N
BAR MAGNETIZED

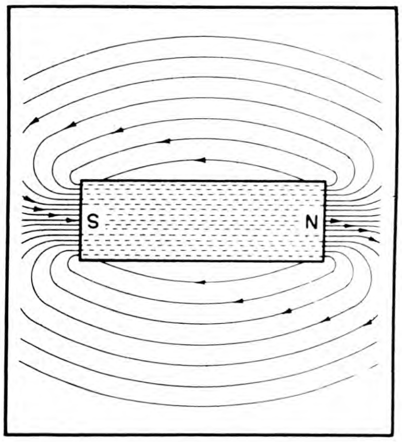
THE DOMAIN THEORY OF MAGNETISM states that if the electrons of the atoms in a material spin more in one direction than in the other, the material will become magnetized.


NUMBER OF ELECTRONS SPINNING COUNTER-CLOCKWISE
NUMBER OF ELECTRONS SPINNING CLOCKWISE
NUCLEUS
K L M N
s sp spd s
+26
3
3
3
3
5
SUBSHELL M_d INCOMPLETE
MOBILE ELECTRONS

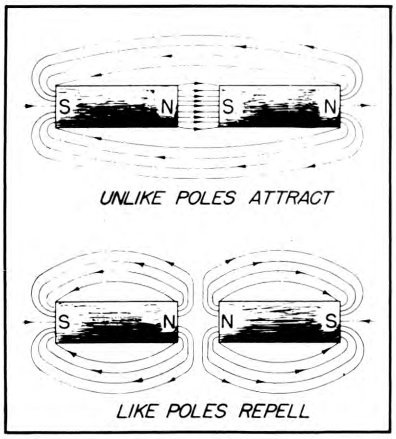
A MAGNETIC FIELD is said to exist in the space surrounding a magnet.


IRON FILINGS
S
N
GLASS PLATE OVER MAGNET

MAGNETIC LINES OF FORCE are imaginary lines used to describe the patterns of the magnetic field about a magnet. These lines are assumed to flow externally from the north pole and into the south pole.



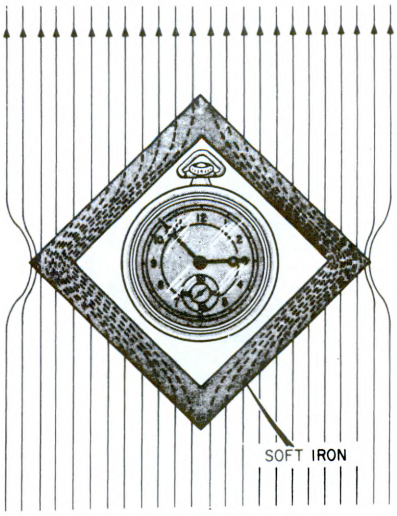
MAGNETIC FLUX is the total number of magnetic lines of force leaving or entering the pole of a magnet.


S
N
S
N
UNLIKE POLES ATTRACT
S
N
N
S
LIKE POLES REPELL

FLUX DENSITY is the number of flux lines per unit area.

FIELD INTENSITY or the intensity of a magnetic field is directly related to the magnetic force exerted by the field.

THE INTENSITY OF ATTRACTION/REPULSION between magnetic poles may be described by a law almost identical to Coulomb's Law of Charged Bodies, that is, the force between two poles is directly proportional to the product of the pole strengths and inversely proportional to the square of the distance between the poles.



MAGNETIC SHIELDING can be accomplished by placing a soft iron shield around the object to be protected, thus directing the lines of force around the object.

MAGNETS ARE CLASSIFIED BY SHAPE and include the bar magnet, the horseshoe magnet, and the ring magnet. The ring magnet is used in computer memory circuits; the horseshoe magnet in some meter circuits.

ENERGY may be defined as the ability to do work.

THE COULOMB (C) is the basic unit used to indicate an electrical charge. One coulomb is equal to a charge of 6.28×10^{18} electrons. When one coulomb of charge exists between two bodies, the electromotive force (or voltage) is one volt.

VOLTAGE is measured as the difference of potential of two charges of interest.

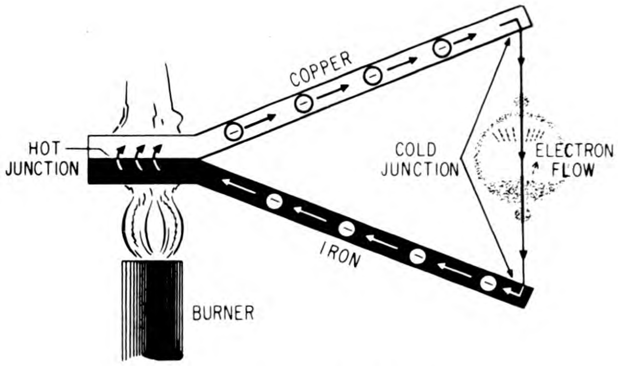
VOLTAGE MEASUREMENTS may be expressed in the following units: volts (V), kilovolts (kV), millivolts (mV), or microvolts (μV).

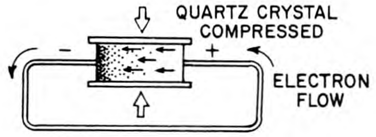
For example:

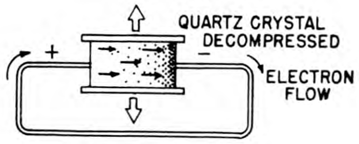
1 kV = 1,000 V
1 mV = 0.001 V
1 μV = 0.000001 V

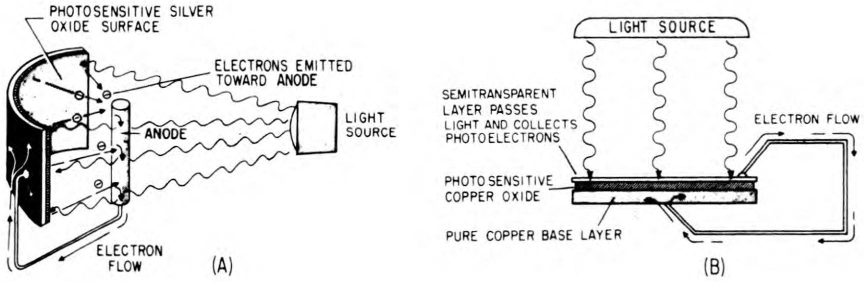
METHODS OF PRODUCING A VOLTAGE include:

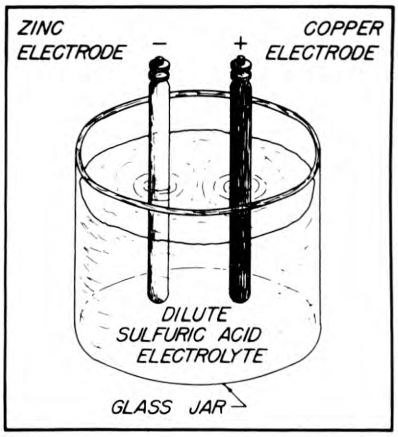
1. Friction
2. Pressure (piezoelectricity)
3. Heat (thermoelectricity)
4. Light (photoelectricity)
5. Chemical action (battery)
6. Magnetism (electromagnetic induction generator)


COPPER
HOT JUNCTION
COLD JUNCTION
ELECTRON FLOW
IRON
BURNER


QUARTZ CRYSTAL COMPRESSED
−
+
ELECTRON FLOW

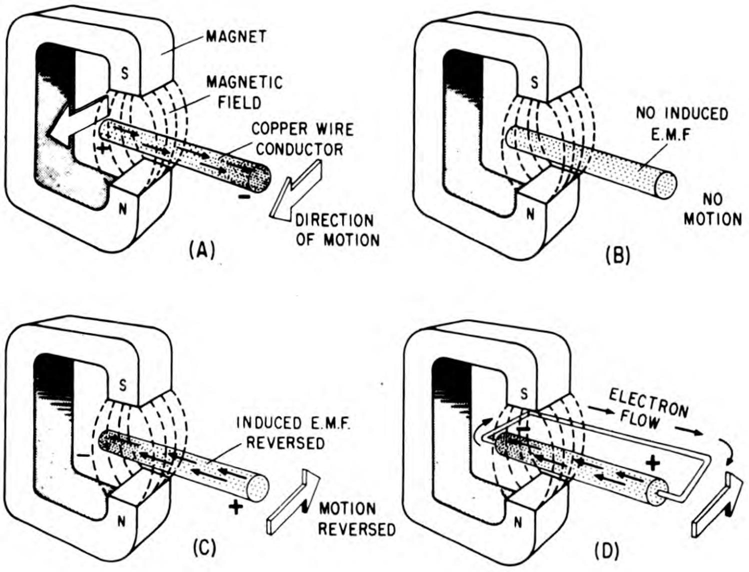

QUARTZ CRYSTAL DECOMPRESSED
+
−
ELECTRON FLOW


PHOTOSENSITIVE SILVER OXIDE SURFACE
ELECTRONS EMITTED TOWARD ANODE
ANODE
LIGHT SOURCE
ELECTRON FLOW
(A)
LIGHT SOURCE
SEMITRANSPARENT LAYER PASSES LIGHT AND COLLECTS PHOTOELECTRONS
ELECTRON FLOW
PHOTOSENSITIVE COPPER OXIDE
PURE COPPER BASE LAYER
(B)


ZINC ELECTRODE
−
+
COPPER ELECTRODE
DILUTE SULFURIC ACID ELECTROLYTE
GLASS JAR

ELECTROMAGNETIC INDUCTION GENERATOR

To produce voltage by use of magnetism, three conditions must be met: There must be a CONDUCTOR in which the voltage will be produced; there must be a MAGNETIC FIELD in the conductor's vicinity; and there must be relative motion between the field and conductor. When these conditions are met, electrons WITHIN THE CONDUCTOR are propelled in one direction or another, creating an electromotive force, or voltage.



ELECTRON CURRENT is based on the assumption that electron current flow is from negative to positive through a circuit.

AN ELECTRIC CURRENT is a directed movement of electrons in a conductor or circuit.

THE AMPERE is the basic unit used to indicate an electric current. A current of one ampere is said to flow when one coulomb of charge (6.28×10^{18} electrons) passes a given point in one second of time. Current measurements may be expressed in the following units: ampere (A), milliampere (mA), and microampere (μA). Current in a circuit increases in direct proportion to the voltage (emf) applied across the circuit.

RESISTANCE is the opposition to current. The ohm is the basic unit of resistance and is represented by the Greek letter omega (Ω). A conductor is said to have one ohm of resistance when an emf of one volt causes one ampere of current to flow in the conductor. Resistance may be expressed in the following units: ohm (Ω), kilohm (kΩ), and megohms (MΩ). For example, $1{,}000{,}000\Omega = 1{,}000\ \text{k}\Omega = 1\text{M}\Omega$.

THE RESISTANCE OF A MATERIAL is determined by the type, the physical dimensions, and the temperature of the material; that is,

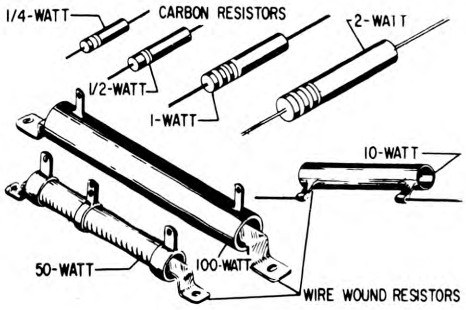
1. A good conductor contains an abundance of free electrons.
2. As the cross-sectional area of given conductor is increased, the resistance will decrease.
3. As the length of a conductor is increased, the resistance will increase.
4. In a material having a positive temperature coefficient, the resistance will increase as the temperature is increased.

THE CONDUCTANCE OF A MATERIAL is the reciprocal of resistance.

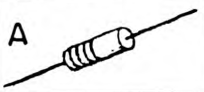
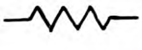
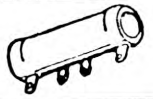
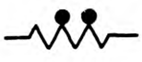
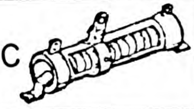
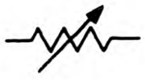
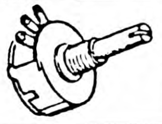
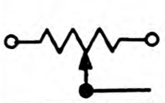
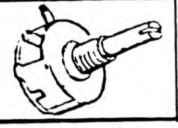
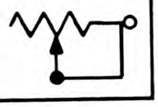
THE UNIT OF CONDUCTANCE is the mho and the symbol is υ.

THE RESISTOR is manufactured to provide a specific value of resistance.

THE CARBON RESISTOR is made of carbon, with fillers and binders blended in to control the ohmic value.



THE RESISTANCE OF A WIREWOUND RESISTOR is determined by the metal content of the wire and the wire's length. Wirewound resistors may be tapped so two or more different voltage values may be taken off the same resistor.

TYPICAL RESISTOR	TYPE	SYMBOL
A 	FIXED CARBON	
B 	FIXED WIREWOUND (TAPPED)	
C 	ADJUSTABLE WIREWOUND	
D 	POTENTIOMETER	
E 	RHEOSTAT	

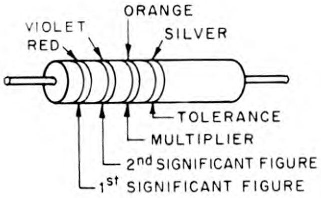
THE POTENTIOMETER AND THE RHEOSTAT are variable resistors and can be adjusted to any resistance value within their ohmic range. The rheostat is usually used for relatively high current applications and has two connections; the potentiometer has 3 connections and is a relatively high-resistance, low-current device.

THE WATTAGE RATING OF A RESISTOR is related to the resistor's physical size, that is, the greater the surface area exposed to the air, the larger the rating.

THE STANDARD COLOR CODE for resistors is used to determine the following:

1. Ohmic value
2. Tolerance
3. Reliability level (on some resistors)

COLOR	SIGNIFICANT FIGURE	DECIMAL MULTIPLIER	RESISTANCE TOLERANCE	RELIABILITY LEVEL PER 1000 HRS.
BLACK	0	1	PERCENT ·	
BROWN	1	10	1	1%
RED	2	100	2	.1%
ORANGE	3	1,000	3	.01%
YELLOW	4	10,000	---	.001%
GREEN	5	100,000		
BLUE	6	1,000,000	---	
VIOLET	7	10,000,000	---	
GRAY	8	100,000,000	---	
WHITE	9	1,000,000,000	---	
GOLD	---	.1	5	
SILVER	---	.01	10	
NO COLOR	---		20	



TOPIC 2

BATTERIES

LEARNING OBJECTIVES

Upon completing this topic you will be able to:

1. State the purpose of a cell.
2. State the purpose of the three parts of a cell.
3. State the difference between the two types of cells.
4. Explain the chemical process that takes place in the primary and secondary cells.
5. Recognize and define the terms electrochemical action, anode, cathode, and electrolyte.
6. State the causes of polarization and local action and describe methods of preventing these effects.
7. Identify the parts of a dry cell.
8. Identify the various dry cells in use today and some of their capabilities and limitations.
9. Identify the four basic secondary cells, their construction, capabilities, and limitations.
10. Define a battery, and identify the three ways of combining cells to form a battery.
11. Describe general maintenance procedures for batteries including the use of the hydrometer, battery capacity, and rating and battery charging.
12. Identify the five types of battery charges.
13. Observe the safety precautions for working with and around batteries.

INTRODUCTION

The purpose of this topic is to introduce and explain the basic theory and characteristics of batteries. The batteries which are discussed and illustrated have been selected as representative of many models and types which are used in the Navy today. No attempt has been made to cover every type of battery in use, however, after completing this topic you will have a good working knowledge of the batteries which are in general use.

First, you will learn about the building block of all batteries, the CELL. The explanation will expore the physical makeup of the cell and the methods used to combine cells to provide useful voltage, current, and power. The chemistry of the cell and how chemical action is used to convert chemical energy to electrical energy are also discussed.

In addition, the care, maintenance, and operation of batteries, as well as some of the safety precautions that should be followed while working with and around batteries are discussed.

Batteries are widely used as sources of direct-current electrical energy in automobiles, boats, aircraft, ships, portable electric/electronic equipment, and lighting equipment. In some instances, they are used as the only source of power; while in others, they are used as a secondary or standby power source.

A battery consists of a number of cells assembled in a common container and connected together to function as a source of electrical power.

THE CELL

A cell is a device that transforms chemical energy into electrical energy. The simplest cell, known as either a galvanic or voltaic cell, is shown in figure 2-1. It consists of a piece of carbon (C) and a piece of zinc (Zn) suspended in a jar that contains a solution of water (H_2O) and sulfuric acid (H_2SO_4) called the electrolyte.

The cell is the fundamental unit of the battery. A simple cell consists of two electrodes placed in a container that holds the electrolyte.

In some cells the container acts as one of the electrodes and, in this case is acted upon by the electrolyte. This will be covered in more detail later.

ELECTRODES

The electrodes are the conductors by which the current leaves or returns to the electrolyte.

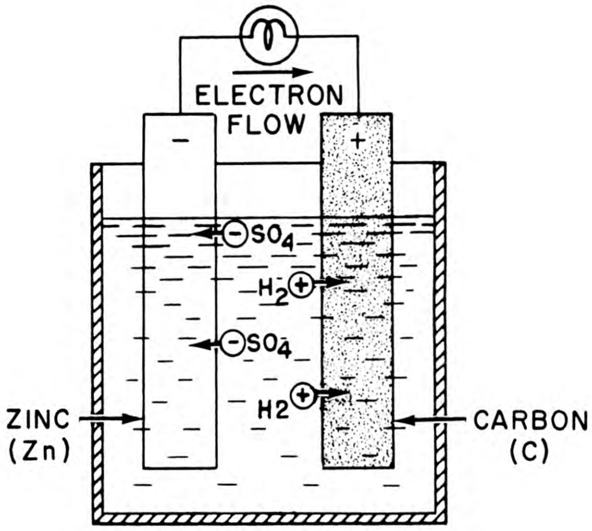


Figure 2-1.—Simple voltaic or galvanic cell.

In the simple cell, they are carbon and zinc strips that are placed in the electrolyte; while in the dry cell (fig. 2-2), they are the carbon rod in the center and zinc container in which the cell is assembled.

ELECTROLYTE

The electrolyte is the solution that acts upon the electrodes. The electrolyte, which provides a path for electron flow, may be a salt, an acid, or an alkaline solution. In the simple galvanic cell the electrolyte is in a liquid form. In the dry cell the electrolyte is a paste.

CONTAINER

The container which may be constructed of one of many different materials provides a means of holding (containing) the electrolyte. The container is also used to mount the electrodes. In the voltaic cell the container must be constructed of a material that will not be acted upon by the electrolyte.

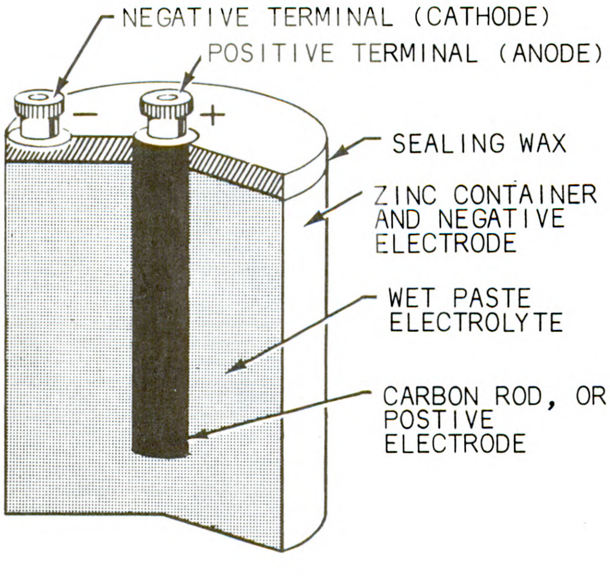

NEGATIVE TERMINAL (CATHODE)
POSITIVE TERMINAL (ANODE)
−
+
SEALING WAX
ZINC CONTAINER AND NEGATIVE ELECTRODE
WET PASTE ELECTROLYTE
CARBON ROD, OR POSTIVE ELECTRODE

Figure 2-2.—Dry cell, cross-sectional view.

Q1. **What is the purpose of a cell?**

Q2. **What are the three parts of a cell?**

Q3. **What is the purpose of each of the three parts of a cell?**

PRIMARY CELL

A primary cell is one in which the chemical action eats away one of the electrodes, usually the negative electrode. When this happens, the electrode must be replaced or the cell must be discarded. In the galvanic-type cell, the zinc electrode and the liquid electrolyte are usually replaced when this happens. In the case of the dry cell, it is usually cheaper to buy a new cell.

SECONDARY CELL

A secondary cell is one in which the electrodes and the electrolyte are altered by the chemical action that takes place when the cell delivers current. These cells may be restored to their original condition by forcing an electric current through them in the direction opposite to that of discharge. The automobile storage battery is a common example of the secondary cell.

Q4. **What are the two types of cells?**

Q5. **What is the main difference between the two types of cells?**

ELECTROCHEMICAL ACTION

If a load (a device that consumes electrical power) is connected externally to the electrodes of a cell, electrons will flow under the influence of a difference in potential across the electrodes from the CATHODE (negative electrode), through the external conductor to the ANODE (positive electrode).

A cell is a device in which chemical energy is converted to electrical energy. This process is called ELECTROCHEMICAL action.

The voltage across the electrodes depends upon the materials from which the electrodes are made and the composition of the electrolyte. The current that a cell delivers depends upon the resistance of the entire circuit, including that of the cell itself. The internal resistance of the cell depends upon the size of the electrodes, the distance between them in the electrolyte, and the resistance of the electrolyte. The larger the electrodes and the closer together they are in the electrolyte (without touching), the lower the internal resistance of the cell and the more current the cell is capable of supplying to the load.

Q6. What is electrochemical action?

Q7. What is another name for the (a) positive electrode, and (b) the negative electrode?

PRIMARY CELL CHEMISTRY

When a current flows through a primary cell having carbon and zinc electrodes and a diluted solution of sulfuric acid and water (combined to form the electrolyte), the following chemical reaction takes place.

The current flow through the load is the movement of electrons from the negative electrode of the cell (zinc) and to the positive electrode (carbon). This causes fewer electrons in the zinc and an excess of electrons in the carbon. Figure 2-1 shows the hydrogen ions (H_2) from the sulfuric acid being attracted to the carbon electrode. Since the hydrogen ions are positively charged they are attracted to the negative charge on the carbon electrode. This negative charge is caused by the excess of electrons. The zinc electrode has a positive charge because it has lost electrons to the carbon electrode. This positive charge attracts the negative ions (SO_4) from the sulfuric acid. The negative ions combine with the zinc to form zinc sulfate. This action causes the zinc electrode to be eaten away. Zinc sulfate is a greyish-white substance that is sometimes seen on the battery post of an automobile battery.

The process of the zinc being eaten away and the sulfuric acid changing to hydrogen and zinc sulfate is the cause of the cell discharging. When the zinc is used up, the voltage of the cell is reduced to zero.

In figure 2-1 you will notice that the zinc electrode is labeled negative and the carbon electrode is labeled positive. This represents the current flow outside the cell from negative to positive.

The zinc combines with the sufuric acid to form zinc sulfate and hydrogen. The zinc sulfate dissolves in the electrolyte (sulfuric acid and water) and the hydrogen appears as gas bubbles around the carbon electrode. As current continues to flow, the zinc gradually dissolves and the solution changes to zinc sulfate and water. The carbon electrode does not enter into the chemical changes taking place, but simply provides a return path for the current.

Q8. In the primary cell, why are negative ions attracted to the negative terminal of the cell?

Q9. How do electrons get from the negative electrode to the positive electrode?

Q10. What causes the negative electrode to be eaten away?

A1. A cell is a device that converts chemical energy to electrical energy.

A2. The electrodes, the electrolyte, and the container.

A3. The electrodes are the current conductors of the cell. The electrolyte is the solution that acts upon the electrodes. The container holds the electrolyte and provides a means of mounting the electrodes.

A4. Primary and secondary.

A5. The secondary cell can be restored to its original condition by an electric current. The primary cell cannot.

A6. The process of converting chemical energy into electrical energy.

A7. (a) the anode, (b) the cathode.

A8. The positive charge caused by electrons leaving the negative electrode attracts the negative ions.

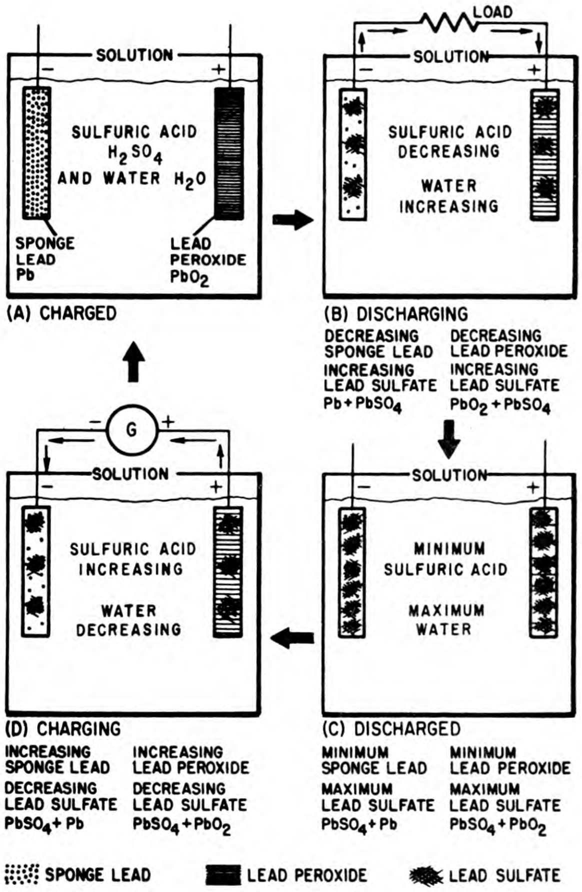
A9. By current flow through the load.

A10. The chemical action between the negative electrode and the electrolyte.

SECONDARY CELL CHEMISTRY

As stated before, the differences between primary and secondary cells are, the secondary cell can be recharged and the electrodes are made of different materials. The secondary cell shown in figure 2-3 uses sponge lead as the cathode and lead peroxide as the anode. This is the lead-acid type cell and will be used to explain the general chemistry of the secondary cell. Later in the topic, when other types of secondary cells are discussed you will see that the materials which make up the parts of a cell are different, but that the chemical action is essentially the same.

Figure 2-3(A) shows a lead-acid secondary cell that is fully charged. The cathode is pure



LOAD
SOLUTION
−
+
SULFURIC ACID
H_2SO_4
AND WATER H_2O
SPONGE LEAD Pb
LEAD PEROXIDE PbO_2
(A) CHARGED
SULFURIC ACID DECREASING
WATER INCREASING
(B) DISCHARGING
DECREASING SPONGE LEAD
DECREASING LEAD PEROXIDE
INCREASING LEAD SULFATE
INCREASING LEAD SULFATE
$Pb + PbSO_4$
$PbO_2 + PbSO_4$
G
SULFURIC ACID INCREASING
WATER DECREASING
(D) CHARGING
INCREASING SPONGE LEAD
INCREASING LEAD PEROXIDE
DECREASING LEAD SULFATE
DECREASING LEAD SULFATE
$PbSO_4 + Pb$
$PbSO_4 + PbO_2$
MINIMUM SULFURIC ACID
MAXIMUM WATER
(C) DISCHARGED
MINIMUM SPONGE LEAD
MINIMUM LEAD PEROXIDE
MAXIMUM LEAD SULFATE
MAXIMUM LEAD SULFATE
$PbSO_4 + Pb$
$PbSO_4 + PbO_2$
SPONGE LEAD
LEAD PEROXIDE
LEAD SULFATE

Figure 2-3.—Secondary cell.

sponge lead, the anode is pure lead peroxide, and the electrolyte is a mixture of sulfuric acid and water.

Figure 2-3(B) shows the secondary cell discharging. A load is connected between the cathode and anode; current flows negative to positive as shown. This current flow creates the same process as was explained for the primary cell with the following exceptions.

In the primary cell the zinc cathode was eaten away by the sulfuric acid. In the secondary cell the sponge-like construction of the cathode retains the lead sulfate formed by the chemical action of the sulfuric acid and the lead. In the primary cell the carbon anode was not chemically acted upon by the sulfuric acid. In the secondary cell the lead peroxide anode is chemically changed to lead sulfate by the sulfuric acid.

When the cell is fully discharged it will be as shown in figure 2-3(C). The anode and cathode retain some lead peroxide and sponge lead but the amounts of lead sulfate in each is maximum. The electrolyte has a minimum amount of sulfuric acid. With this condition no further chemical action can take place within the cell.

As you know, the secondary cell can be recharged. Recharging is the process of reversing the chemical action that occurs as the cell discharges. To recharge the cell, a voltage source, such as a generator, is connected as shown in figure 2-3(D). The negative terminal of the voltage source is connected to the cathode of the cell and the positive terminal of the voltage source is connected to the anode of the cell. With this arrangement the lead sulfate is chemically changed back to sponge lead in the cathode, lead peroxide in the anode, and sulfuric acid in the electrolyte. After all the lead sulfate is chemically changed, the cell is fully charged as shown in figure 2-3(A). Once the cell has been charged, the discharge-charge cycle may be repeated.

Q11. Refer to figure 2-3(B). Why is the sulfuric acid decreasing?

Q12. Refer to figure 2-3(D). How is it possible for the sulfuric acid to be increasing?

Q13. Refer to figure 2-3(D). When all the lead sulfate has been converted, what is the condition of the cell?

POLARIZATION OF THE CELL

The chemical action that occurs in the cell while the current is flowing causes hydrogen bubbles to form on the surface of the anode. This action is called POLARIZATION. Some hydrogen bubbles rise to the surface of the electrolyte and escape into the air, some remain on the surface of the anode. If enough bubbles remain around the anode, the bubbles form a barrier that increases internal resistance. When the internal resistance of the cell increases, the output current is decreased and the voltage of the cell also decreases.

A cell that is heavily polarized has no useful output. There are several methods to prevent polarization or to depolarize the cell.

One method uses a vent on the cell to permit the hydrogen to escape into the air. A disadvantage of this method is that hydrogen is not available to reform into the electrolyte during recharging. This problem is solved by adding water to the electrolyte, such as in an automobile battery. A second method is to use material that is rich in oxygen, such as manganese dioxide, which supplies free oxygen to combine with the hydrogen and form water.

A third method is to use a material that will absorb the hydrogen, such as calcium. The calcium releases hydrogen during the charging process. All three methods remove enough hydrogen so that the cell is practically free from polarization.

LOCAL ACTION

When the external circuit is removed, the current ceases to flow, and, theoretically, all chemical action within the cell stops. However,

A11. **The sulfuric acid is chemically acting upon the anode and cathode which creates a current flow through the load.**

A12. **The charging currents causes the lead sulfate in the anode and cathode to be changed back to lead peroxide, sponge lead, and sulfuric acid.**

A13. **Fully charged.**

---

commerical zinc contains many impurities, such as iron, carbon, lead, and arsenic. These impurities form many small electrical cells within the zinc electrode in which current flows between the zinc and its impurities. Thus, the chemical action continues even though the cell itself is not connected to a load.

Local action may be prevented by using pure zinc (which is not practical), by coating the zinc with mercury, or by adding a small percentage of mercury to the zinc during the manufacturing process. The treatment of the zinc with mercury is called amalgamating (mixing) the zinc. Since mercury is many times heavier than an equal volume of water, small particles of impurities weighing less than mercury will float to the surface of the mercury. The removal of these impurities from the zinc prevents local action. The mercury is not readily acted upon by the acid. When the cell is delivering current to a load, the mercury continues to act on the impurities in the zinc. This causes the impurities to leave the surface of the zinc electrode and float to the surface of the mercury. This process greatly increases the storage life of the cell.

Q14. **Describe three ways to prevent polarization.**

Q15. **Describe local action.**

TYPES OF CELLS

The development of new and different types of cells in the past decade has been so rapid that it is virtually impossible to have a complete knowledge of all the various types. A few recent developments are the silver-zinc, nickel-zinc, nickel-cadmium, silver-cadmium, organic and inorganic lithium and mercury cells.

PRIMARY DRY CELL

The dry cell is the most popular type of primary cell. It is ideal for simple applications where an inexpensive and noncritical source of electricity is all that is needed.

The dry cell is not actually dry. The electrolyte is not in a liquid state, but is a moist paste. If it should become totally dry, it would no longer be able to transform chemical energy to electrical energy.

Construction of a Dry Cell

The construction of a common type of dry cell is shown in figure 2-4. These dry cells are also referred to as Leclanche′ cells. The internal parts of the cell are located in a cylindrical zinc container. This zinc container serves as the negative electrode (cathode) of the cell. The container is lined with a nonconducting material, such as blotting paper, to separate the zinc from the paste. A carbon electrode is located in the center, and it serves as the positive terminal (anode) of the cell. The paste is a mixture of several substances such as ammonium chloride, powdered coke, ground carbon, manganese dioxide, zinc chloride, graphite, and water.

This paste, which is packed in the space between the anode and the blotting paper, also serves to hold the anode rigid in the center of the cell. When the paste is packed in the cell, a small space is left at the top for expansion of the electrolytic paste caused by the depolarization action. The cell is then sealed with a cardboard or plastic seal.

Since the zinc container is the cathode, it must be protected with some insulating material

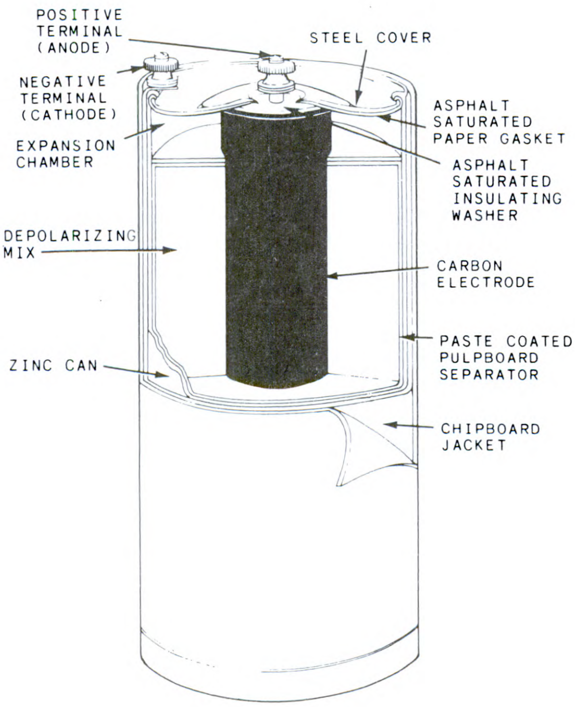

POSITIVE TERMINAL (ANODE)
STEEL COVER
NEGATIVE TERMINAL (CATHODE)
EXPANSION CHAMBER
ASPHALT SATURATED PAPER GASKET
ASPHALT SATURATED INSULATING WASHER
DEPOLARIZING MIX
CARBON ELECTRODE
PASTE COATED PULPBOARD SEPARATOR
ZINC CAN
CHIPBOARD JACKET

Figure 2-4.—Cutaway view of the general-purpose dry cell.

to be electrically isolated. Therefore, it is common practice for the manufacturer to enclose the cells in cardboard and metal containers.

The dry cell (fig. 2-4) is basically the same as the simple voltaic cell (wet cell) described earlier, as far as its internal chemical action is concerned. The action of the water and the ammonium chloride in the paste, together with the zinc and carbon electrodes, produces the voltage of the cell. Manganese dioxide is added to reduce polarization when current flows and zinc chloride reduces local action when the cell is not being used.

A cell that is not being used (sitting on the shelf) will gradually deteriorate because of slow internal chemical changes (local action). This deterioration is usually very slow if cells are properly stored. If unused cells are stored in a cool place, their shelf life will be greatly increased. Therefore, to minimize deterioration, they should be stored in refrigerated spaces.

The blotting paper (paste-coated pulpboard separator) serves two purposes—(1) it keeps the paste from making actual contact with the zinc container and (2) it permits the electrolyte from the paste to filter through to the zinc slowly. The cell is sealed at the top to keep air from entering and drying the electrolyte. Care should be taken to prevent breaking this seal.

Q16. What serves as the cathode of a dry cell?

Q17. Why is a dry cell called a DRY cell?

Q18. What does the term "shelf life" mean?

Mercuric-Oxide Zinc Cell

The mercuric-oxide zinc cell (mercury cell) is a primary cell that was developed during World War II. Two important assets of the mercury cell are, its ability to produce current for a long period of time and a long shelf life when compared to the dry cell shown in figure 2-4. The mercury cell also has a very stable output voltage and is a power source that can be made in a small physical size.

With the birth of the space program and the development of small transceivers and miniaturized equipment, a power source of small size was needed. Such equipment requires a small cell which is capable of delivering maximum electrical energy at a constant discharge voltage. The mercury cell, which is one of the smallest cells, meets these requirements.

Present mercury cells are manufactured in three basic types as shown in figure 2-5. The wound-anode type, shown in figure 2-5(A), has an anode composed of a corrugated zinc strip with a paper absorbent. The zinc is mixed with mercury, and the paper is soaked in the electrolyte which causes it to swell and press against the zinc and make positive contact. This

A14. Vent the cell, add a material rich in oxygen, and use a material that will absorb hydrogen.

A15. Current flow in a cell with no external load.

A16. The zinc container.

A17. The electrolyte is not a liquid but is in the form of a paste.

A18. The period that a cell can be stored and still be useable.

---

process insures that the electrolyte makes contact with the anode.

In the pressed-powder cells, shown in figure 2-5(B) and (C), the zinc powder for the anode is mixed prior to being pressed into shape. The absorbent shown in the figure is paper soaked in the electrolyte. The space between the inner and outer containers provides passage for any gas generated by an improper chemical balance or impurities present within the cell.

If the anode and cathode of a cell are connected together without a load, a SHORT CIRCUIT condition exists. Short circuits (shorts) can be very dangerous. They cause excessive heat, pressure, and current flow which may cause serious damage to the cell or be a safety hazard to personnel.

WARNING

DO NOT SHORT THE MERCURY CELL. SHORTED MERCURY CELLS HAVE EXPLODED WITH CONSIDERABLE FORCE.

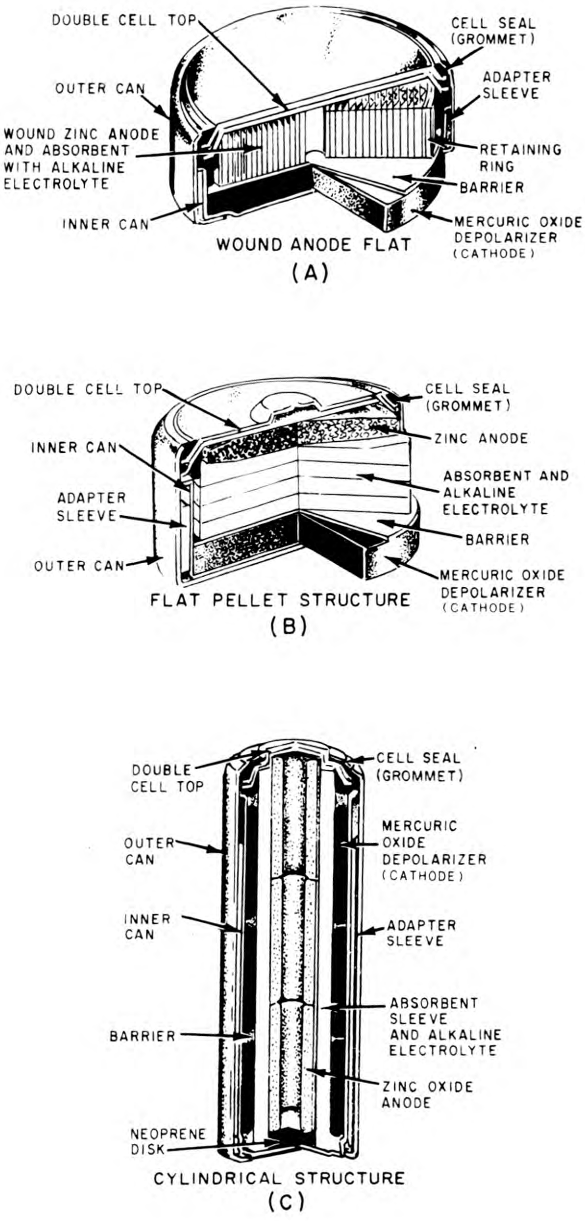

DOUBLE CELL TOP
CELL SEAL (GROMMET)
OUTER CAN
ADAPTER SLEEVE
WOUND ZINC ANODE AND ABSORBENT WITH ALKALINE ELECTROLYTE
RETAINING RING
BARRIER
INNER CAN
MERCURIC OXIDE DEPOLARIZER (CATHODE)
WOUND ANODE FLAT
(A)
DOUBLE CELL TOP
CELL SEAL (GROMMET)
INNER CAN
ZINC ANODE
ABSORBENT AND ALKALINE ELECTROLYTE
ADAPTER SLEEVE
BARRIER
OUTER CAN
MERCURIC OXIDE DEPOLARIZER (CATHODE)
FLAT PELLET STRUCTURE
(B)
DOUBLE CELL TOP
CELL SEAL (GROMMET)
OUTER CAN
MERCURIC OXIDE DEPOLARIZER (CATHODE)
INNER CAN
ADAPTER SLEEVE
ABSORBENT SLEEVE AND ALKALINE ELECTROLYTE
BARRIER
ZINC OXIDE ANODE
NEOPRENE DISK
CYLINDRICAL STRUCTURE
(C)

Figure 2-5.—Mercury cells.

Other Types of Cells

There are many different types of primary cells. Because of such factors as cost, size, ease of replacement, and voltage or current needs, many types of primary cells have been developed. The following is a brief description of some of the primary cells in use today.

The Manganese Dioxide-Alkaline-Zine Cell is similar to the zinc-carbon cell except for the electrolyte used. This type of cell offers better voltage stability and longer life than the zinc-carbon type. It also has a longer shelf life and can operate over a wide temperature range. The manganese dioxide-alkaline-zinc cell has a voltage of 1.5 volts and is available in a wide range of sizes. This cell is commonly referred to as the alkaline cell.

The Magnesium-Manganese Dioxide Cell uses magnesium as the anode material. This allows a higher output capacity over an extended period of time compared to the zinc-carbon cell. This cell produces a voltage of approximately 2 volts. The disadvantage of this type of cell is the production of hydrogen during its operation.

The Lithium-Organic Cell and the Lithium-Inorganic Cell, are recent developments of a new line of high-energy cells. The main advantages of these types of cells are, very high power, operation over a wide temperature range, they are lighter than most cells, and have a remarkably long shelf life of up to 20 years.

CAUTION

Lithium cells contain toxic materials under pressure. Do not puncture, recharge, short-circuit, expose to excessively high temperatures, or incinerate. Use these batteries/cells only in approved equipment. Do not throw in trash.

Q19. Why should a mercury cell NOT be shorted?

Q20. What factors should be considered when selecting a primary cell for a power source?

SECONDARY WET CELLS

Secondary cells are sometimes known as wet cells. There are four basic type of wet cells, the lead-acid, nickel-cadmium, silver-zinc, and silver-cadmium.

Lead-Acid Cell

The lead-acid cell is the most widely used secondary cell. The previous explanation of the secondary cell describes exactly the manner in which the lead-acid cell provides electrical power. The discharging and charging action presented in electrochemical action describes the lead-acid cell.

You should recall that the lead-acid cell has an anode of lead peroxide, a cathode of sponge lead, and the electrolyte is sulfuric acid and water.

Nickel-Cadmium Cell

The nickel-cadmium cell (NICAD) is far superior to the lead-acid cell. In comparison to lead-acid cells, these cells generally require less maintenance throughout their service life in regard to the adding of electrolyte or water. The major difference between the nickel-cadmium cell and the lead-acid cell is the material used in the cathode, anode, and electrolyte. In the nickel-cadimum cell the cathode is cadmium hydroxide, the anode is nickel hydroxide, and the electrolyte is potassium hydroxide and water.

The nickel-cadmium and lead-acid cells have capacities that are comparable at normal discharge rates, but at high discharge rates the nickel-cadmium cell can deliver a larger amount of power. In addition the nickel-cadmium cell can:

1. Be charged in a shorter time.
2. Stay idle longer in any state of charge and keep a full charge when stored for a longer period of time.
3. Be charged and discharged any number of times without any appreciable damage.

Due to their superior capabilities, nickel-cadmium cells are being used extensively in many military applications that require a cell with a high discharge rate. A good example is in the aircraft storage battery.

Silver-Zinc Cells

The silver-zinc cell is used extensively to power emergency equipment. This type of cell is relatively expensive and can be charged and discharged fewer times than other types of cells.

A19. The danger of explosion.

A20. Cost, size, ease of replacement, and voltage or current needs.

When compared to the lead-acid or nickel-cadmium cells these disadvantages are overweighed by the light weight, small size, and good electrical capacity of the silver-zinc cell.

The silver-zinc cell uses the same electrolyte as the nickel-cadmium cell (potassium hydroxide and water) but the anode and cathode differ from the nickel-cadmium cell. The anode is composed of silver oxide and the cathode is made of zinc.

Silver-Cadmium Cell

The silver-cadmium cell is a fairly recent development for use in storage batteries. The silver-cadmium cell combines some of the better features of the nickel-cadmium and silver-zinc cells. It has more than twice the shelf life of the silver-zinc cell, and can be recharged many more times. The disadvantages of the silver-cadmium cell are high cost and low voltage production.

The electrolyte of the silver-cadmium cell is potassium hydroxide and water as in the nickel-cadmium and silver-zinc cells. The anode is silver oxide as in the silver-zinc cell and the cathode is cadmium hydroxide as in the nicad cell. You may notice that different combinations of materials are used to form the electrolyte, cathode, and anode of different cells. These combinations provide the cells with different qualities for many varied applications.

Q21. What are the four basic types of secondary (wet) cells?

Q22. What are the advantages of a nicad cell over a lead-acid cell?

Q23. What type of cell is most commonly used for emergency systems?

Q24. What three cells use the same electrolyte?

BATTERIES

A battery is a voltage source that uses chemical action to produce a voltage. In many cases the term battery is applied to a single cell, such as the flashlight battery. In the case of a flashlight that uses a battery of 1.5 volts, the battery is a single cell. The flashlight that is operated by 6 volts uses 4 cells in a single case and this is a battery composed of more than one cell. There are three ways to combine cells to form a battery.

COMBINING CELLS

In many cases, a battery-powered device may require more electrical energy than one cell can provide. The device may require either a higher voltage or more current, and in some cases both. Under such conditions it is necessary to combine, or interconnect, a sufficient number of cells to meet the higher requirements. Cells connected in SERIES provide a higher voltage, while cells connected in PARALLEL provide a higher current capacity. To provide adequate power when both voltage and current requirements are greater than the capacity of one cell, a combination SERIES-PARALLEL network of cells must be used.

Series-Connected Cells

Assume that a load requires a power supply of 6 volts and a current capacity of 1/8 ampere. Since a single cell normally supplies a voltage of only 1.5 volts, more than one cell is needed. To obtain the higher voltage, the cells are connected in series as shown in figure 2-6.

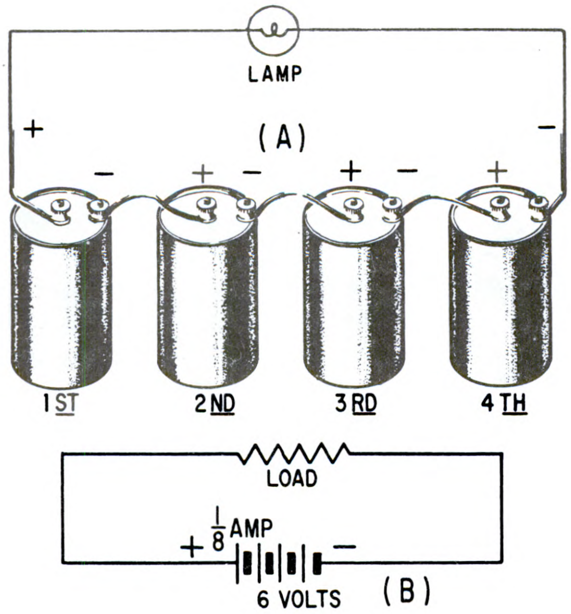


Figure 2-6.—(A) Pictorial view of series-connected cells; (B) Schematic of series connection.

Figure 2-6(B) is a schematic representation of the circuit shown in figure 2-6(A). The load is shown by the resistance symbol and the battery is indicated by one long and one short line per cell.

In a series hookup, the negative electrode (cathode) of the first cell is connected to the positive electrode (anode) of the second cell, the negative electrode of the second to the positive of the thrid, etc. The positive electrode of the first cell and negative electrode of the last cell then serve as the terminals of the battery. In this way, the voltage is 1.5 volts for each cell in the series line. There are four cells, so the output terminal voltage is 1.5 x 4, or 6 volts. When connected to the load, 1/8 ampere flows through the load and each cell of the battery. This is within the capacity of each cell. Therefore, only four series-connected cells are needed to supply this particular load.

CAUTION

WHEN CONNECTING CELLS IN SERIES, CONNECT ALTERNATE TERMINALS TOGETHER (- to +, - to +, etc.) ALWAYS HAVE TWO REMAINING TERMINALS THAT ARE USED FOR CONNECTION TO THE LOAD ONLY. DO NOT CONNECT THE TWO REMAINING TERMINALS TOGETHER AS THIS IS A SHORT ACROSS THE BATTERY AND WOULD NOT ONLY QUICKLY DISCHARGE THE CELLS BUT COULD CAUSE SOME TYPES OF CELLS TO EXPLODE.

Parallel-Connected Cells

In this case, assume an electrical load requires only 1.5 volts, but will require 1/2 ampere of current. (Assume that a single cell will supply only 1/8 ampere.) To meet this requirement, the cells are connected in parallel, as shown in figure 2-7(A) and schematically represented in 2-7(B). In a parallel connection, all positive cell electrodes are connected to one line, and all negative electrodes are connected to the other. No more than one cell is connected between the lines at any one point; so the voltage between the lines is the same as that of one cell, or 1.5 volts. However, each cell may contribute its maximum allowable current of 1/8 ampere to the line. There are four cells, so the total line current is 1/8 x 4, or 1/2 ampere. In this case four cells in parallel have enough capacity to supply a load requiring 1/2 ampere at 1.5 volts.

Series-Parallel-Connected Cells

Figure 2-8 depicts a battery network supplying power to a load requiring both a voltage and current greater than one cell can provide. To provide the required 4.5 volts, groups of three 1.5-volt cells are connected in series. To provide the required 1/2 ampere of current, four series groups are connected in parallel, each supplying 1/8 ampere of current.

A21. Lead-Acid, Nickel-Cadmium (NICAD), Silver-Zinc, and Silver-Cadmium.

A22. Can be charged in a shorter time, can deliver a larger amount of power, and stays idle longer.

A23. Silver-Zinc cell.

A24. Silver-Cadmium, Silver-Zinc, and Nickel-Cadmium.

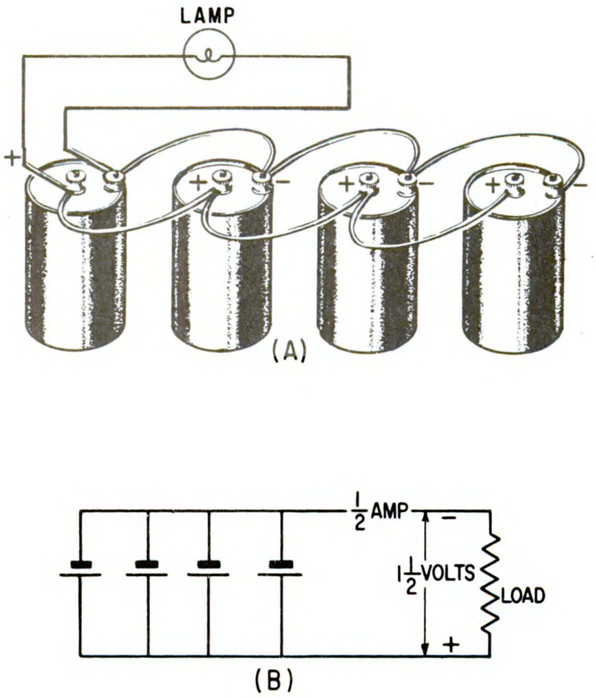

LAMP
+
+
–
+
–
+
–
(A)
$\frac{1}{2}$ AMP
–
$1\frac{1}{2}$ VOLTS
LOAD
+
(B)

Figure 2-7.—(A) Pictorial view of parallel-connected cells; (B) Schematic of parallel connection.

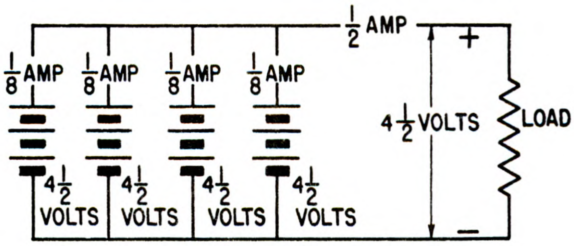

$\frac{1}{2}$ AMP
+
$\frac{1}{8}$ AMP
$\frac{1}{8}$ AMP
$\frac{1}{8}$ AMP
$\frac{1}{8}$ AMP
$4\frac{1}{2}$ VOLTS
LOAD
$4\frac{1}{2}$ VOLTS
$4\frac{1}{2}$ VOLTS
$4\frac{1}{2}$ VOLTS
$4\frac{1}{2}$ VOLTS
–

Figure 2-8.—Schematic of series-parallel connected cells.

The connections shown have been used to illustrate the various methods of combining cells to form a battery. Series, parallel, and series-parallel circuits will be covered in detail in the next topic, Direct Current.

Some batteries are made from primary cells. When a primary-cell battery is completely discharged, the entire battery must be replaced. Because there is nothing else that can be done to primary cell batteries, the rest of the discussion on batteries will be concerned with batteries made of secondary cells.

Q25. What does the term battery normally refer to?

Q26. What are the three ways of combining cells, and what is each used for?

BATTERY CONSTRUCTION

Secondary cell batteries are constructed using the various secondary cells already described. The lead-acid battery is one of the most common batteries in use today and will be used to explain battery construction. The nickel-cadmium battery is being used with increasing frequency and will also be discussed.

Figure 2-9 shows the makeup of a lead-acid battery. The container houses the separate cells. Most containers are hard rubber, plastic, or some

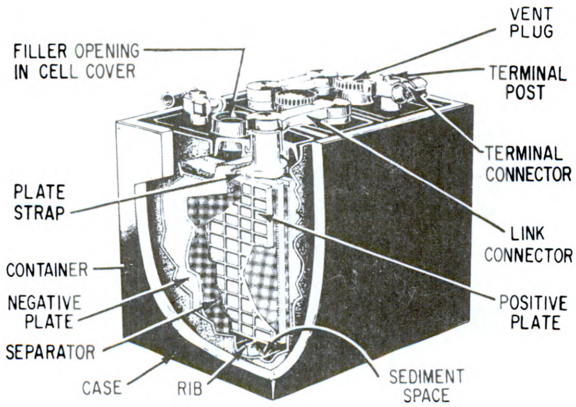

VENT PLUG
FILLER OPENING IN CELL COVER
TERMINAL POST
TERMINAL CONNECTOR
PLATE STRAP
LINK CONNECTOR
CONTAINER
NEGATIVE PLATE
POSITIVE PLATE
SEPARATOR
CASE
RIB
SEDIMENT SPACE

Figure 2-9.—Lead-acid battery construction.

other material that is resistant to the electrolyte and mechanical shock, and will withstand extreme temperatures. The container (battery case) is vented through vent plugs to allow the gases that form within the cells to escape. The plates in the battery are the cathodes and anodes that were discussed earlier. In figure 2-10 the negative plate group is the cathode of the individual cells and the positive plate group is the anode. As shown in the figure the plates are interlaced with a terminal attached to each plate group. The terminals of the individual cells are connected together by link connectors as shown in figure 2-9. The cells are connected in series in the battery and the positive terminal of one end cell becomes the positive terminal of the battery. The negative terminal of the opposite end cell becomes the negative terminal of the battery.

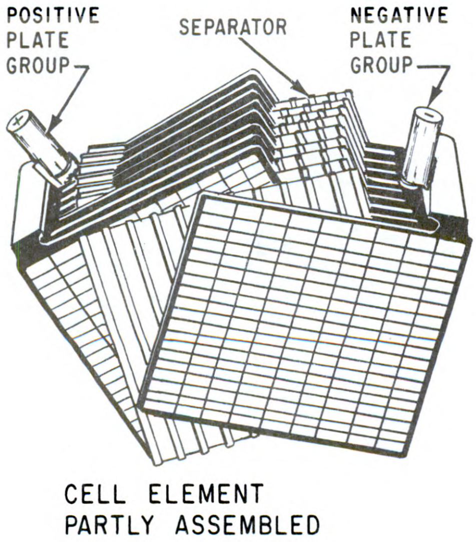

POSITIVE PLATE GROUP
SEPARATOR
NEGATIVE PLATE GROUP
CELL ELEMENT PARTLY ASSEMBLED

Figure 2-10.—Lead-acid battery plate arrangement.

The terminals of a lead-acid battery are usually identified from one another by their size and markings. The positive terminal, marked (+) is sometimes colored red and is physically larger than the negative terminal, marked (-).

The individual cells of the lead-acid battery are not replaceable so in the event one cell fails the battery must be replaced.

The nickel-cadmium battery is similar in construction to the lead-acid battery with the exception that it has individual cells which can be replaced. The cell of the nicad battery is shown in figure 2-11.

The construction of secondary cell batteries is so similar, that it is difficult to distinguish the type of battery by simply looking at it. The type of battery must be known to properly check or recharge the battery. Each battery should have a nameplate that gives a description of its type and electrical characteristics.

Q27. Other than the type of cell used, what is the major difference between the construction of the lead-acid and nicad battery?

Q28. How is the type of battery most easily determined?

BATTERY MAINTENANCE

The following information concerns the maintenance of secondary-cell batteries and is of a general nature. You must check the

A25. A voltage source in a single container made from one or more cells.

A26. Series, to increase voltage but not current. Parallel, to increase current but not voltage. Series-Parallel, to increase both current and voltage.

A27. The cells in the nicad battery can be replaced.

A28. By looking at the name plate data.

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appropriate technical manuals for the specific type of battery prior to performing maintenance on any battery.

The Hydrometer

A HYDROMETER is the instrument used to measure the amount of active ingredients in the electrolyte of the battery. The hydrometer measures the SPECIFIC GRAVITY of the electrolyte. Specific gravity is the ratio of the weight of the electrolyte to the weight of the same volume of pure water. The active ingredient, such as sulfuric acid or potassium hydroxide, is heavier than water. Because the active ingredient is heavier than water, the more active ingredient there is in the electrolyte, the heavier the electrolyte will be; the heavier the electrolyte, the higher the specific gravity.

A hydrometer, shown in figure 2-12, is a glass syringe with a float inside it. The float is a hollow glass tube weighted at one end and sealed at both ends, with a scale calibrated in specific gravity marked on the side. The electrolyte to be tested is drawn into the hydrometer by using the suction bulb. Enough electrolyte should be drawn into the hydrometer so that the float will rise; the hydrometer should not be filled to the extent that the float rises into the suction bulb.

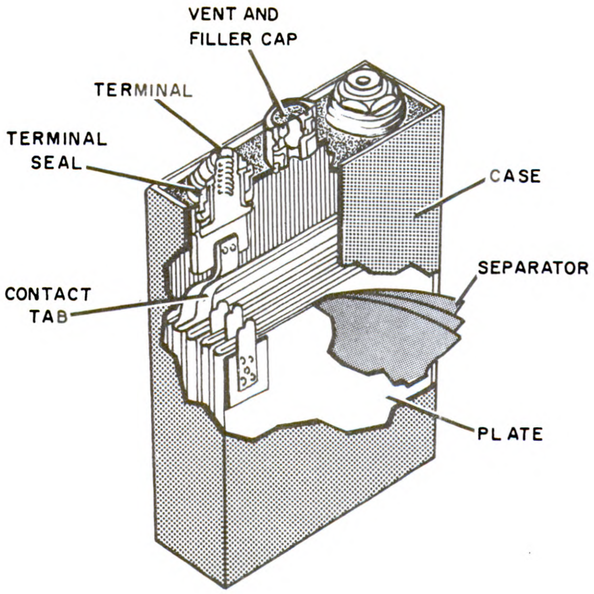


Figure 2-11.—Nickel-cadmium cell.

Since the weight of the float is at its base, the float will rise to a point determined by the weight of the electrolyte. If the electrolyte contains a large concentration of active ingredient, the float will rise higher than if the electrolyte has a small concentration of active ingredient.

To read the hydrometer, hold it in a vertical position and take the reading at the level of the electrolyte. The manufacturer's technical manual for battery specifications should be referred to for the correct specific gravity ranges.

Note: Hydrometers should be flushed with fresh water after each use to prevent inaccurate readings. Storage battery hydrometers must not be used for any other purpose.

Q29. What is the purpose of the hydrometer?

Q30. Which electrolyte has more active ingredient? Electrolyte A, specific gravity 1.015? Electrolyte B, specific gravity 1.125

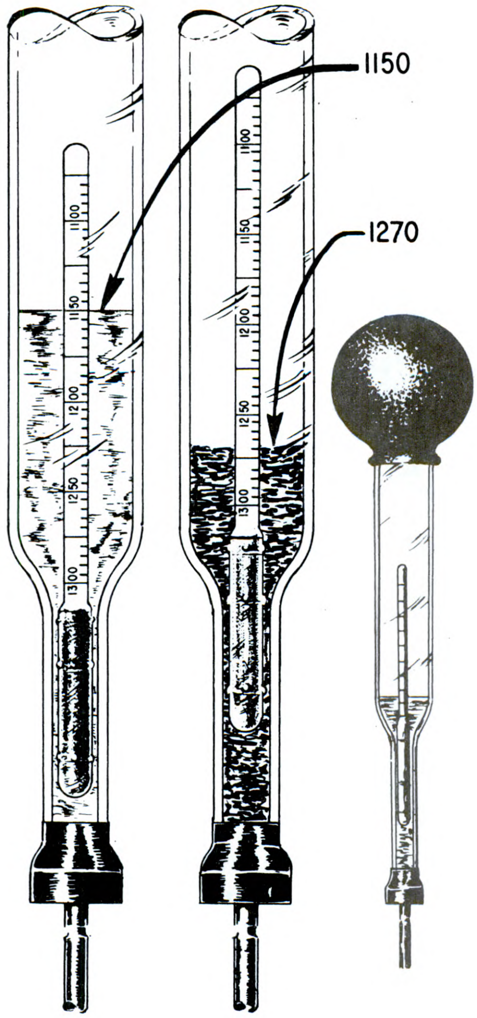


Figure 2-12.—Hydrometer.

Other Maintenance

The routine maintenance of a battery is very simple. Terminals should be checked periodically for cleanliness and good electrical connection. The battery case should be inspected for cleanliness and evidence of damage. The level of electrolyte should be checked and if the electrolyte is low, distilled water should be added to bring the electrolyte to the proper level. Maintenance procedures for batteries are normally determined by higher authority and each command will have detailed procedures for battery care and maintenance.

Safety Precautions With Batteries

All types of batteries should be handled with care.

1. NEVER SHORT THE TERMINALS OF A BATTERY.
2. CARRYING STRAPS SHOULD BE USED WHEN TRANSPORTING BATTERIES.
3. PROTECTIVE CLOTHING, SUCH AS RUBBER APRON, RUBBER GLOVES, AND A FACE SHIELD SHOULD BE WORN WHEN WORKING WITH BATTERIES.
4. NO SMOKING, ELECTRIC SPARKS, OR OPEN FLAMES SHOULD BE PERMITTED NEAR CHARGING BATTERIES.
5. CARE SHOULD BE TAKEN TO PREVENT SPILLING OF THE ELECTROLYTE.

In the event electrolyte is splashed or spilled on a surface, such as the floor or table, it should be diluted with large quantities of water and cleaned up immediately.

If the electrolyte is spilled or splashed on the skin or eyes, IMMEDIATELY flush the skin or eyes with large quantities of fresh water for a minimum of 15 minutes. If the electrolyte is in the eyes, be sure the upper and lower eyelids are pulled out sufficiently to allow the fresh water to flush under the eyelids. The medical department should be notified as soon as possible and informed of the type of electrolyte and the location of the accident.

CAPACITY AND RATING OF BATTERIES

The CAPACITY of a battery is measured in ampere-hours. The ampere-hour capacity is equal to the product of the current in amperes and the time in hours during which the battery will supply this current. The ampere-hour capacity varies inversely with the discharge current. For example, a 400 ampere-hour battery will deliver 400 amperes for 1 hour or 100 amperes for 4 hours.

Storage batteries are RATED according to their rate of discharge and ampere-hour capacity. Most batteries are rated according to a

A29. To measure the amount of active ingredient in the electrolyte.

A30. Electrolyte B. It is heavier per unit volume.

20-hour rate of discharge. That is, if a fully charged battery is completely discharged during a 20-hour period, it is discharged at the 20-hour rate. Thus, if a battery can deliver 20 amperes continuously for 20 hours, the battery has a rating of 20 amperes x 20 hours, or 400 ampere-hours. Therefore, the 20-hour rating is equal to the average current that a battery is capable of supplying without interruption for an interval of 20 hours. (Note: Aircraft batteries are rated according to a 1-hour rate of discharge.)

All standard batteries deliver 100 percent of their available capacity if discharged in 20 hours or more, but they will deliver less than their available capacity if discharged at a faster rate. The faster they discharge, the less ampere-hour capacity they have.

The low-voltage limit, as specified by the manufacturer, is the limit beyond which very little useful energy can be obtained from a battery. This low-voltage limit is normally a test used in battery shops to determine the condition of a battery.

Q31. When should safety precautions pertaining to batteries be observed?

Q32. How long should a 200 ampere-hour battery be able to deliver 5 amperes?

BATTERY CHARGING

It should be remembered that adding the active ingredient to the electrolyte of a discharged battery does not recharge the battery. Adding the active ingredient only increases the specific gravity of the electrolyte and does not convert the plates back to active material, and so does not bring the battery back to a charged condition. A charging current must be passed through the battery to recharge it.

Batteries are usually charged in battery shops. Each shop will have specific charging procedures for the types of batteries to be charged. The following discussion will introduce you to the types of battery charges.

The following types of charges may be given to a storage battery, depending upon the condition of the battery:

1. Initial charge
2. Normal charge
3. Equalizing charge
4. Floating charge
5. Fast charge

Initial Charge

When a new battery is shipped dry, the plates are in an uncharged condition. After the electrolyte has been added, it is necessary to charge the battery. This is accomplished by giving the battery a long low-rate initial charge. The charge is given in accordance with the manufacturer's instructions, which are shipped with each battery. If the manufacturer's instructions are not available, reference should be made to the detailed instructions for charging batteries found in current Navy directives.

Normal Charge

A normal charge is a routine charge that is given in accordance with the nameplate data during the ordinary cycle of operation to restore the battery to its charged condition.

Equalizing Charge

An equalizing charge is a special extended normal charge that is given periodically to batteries as part of a maintenance routine. It insures that all the sulfate is driven from the plates and that all the cells are restored to a maximum specific gravity. The equalizing charge is continued until the specific gravity of all cells, corrected for temperature, shows no change for a 4-hour period.

Floating Charge

In a floating charge, the charging rate is determined by the battery voltage rather than by a definite current value. The floating charge is used to keep a battery at full charge while the battery is idle or in light duty. It is sometimes referred to as a trickle charge and is accomplished with low current.

Fast Charge

A fast charge is used when a battery must be recharged in the shortest possible time. The charge starts at a much higher rate than is normally used for charging. It should be used only in an emergency, as this type charge may be harmful to the battery.

Charging Rate

Normally, the charging rate of Navy storage batteries is given on the battery nameplate. If the available charging equipment does not have the desired charging rates, the nearest available rates should be used. However, the rate should never be so high that violent gassing (explained later in this text) occurs.

Charging Time

The charge must be continued until the battery is fully charged. Frequent readings of specific gravity should be taken during the charge, and compared with the reading taken before the battery was placed on charge.

Gassing

When a battery is being charged, a portion of the energy breaks down the water in the electrolyte. Hydrogen is released at the negative plates and oxygen at the positive plates. These gases bubble up through the electrolyte and collect in the air space at the top of the cell. If violent gassing occurs when the battery is first placed on charge, the charging rate is too high. If the rate is not too high, steady gassing develops as the charging proceeds, indicating that the battery is nearing a fully charged condition.

WARNING

A MIXTURE OF HYDROGEN AND AIR CAN BE DANGEROUSLY EXPLOSIVE. NO SMOKING, ELECTRIC SPARKS, OR OPEN FLAMES SHOULD BE PERMITTED NEAR CHARGING BATTERIES.

Q33. Can a battery be recharged by adding more electrolyte?

Q34. If violent gassing occurs during a battery charge, what action should be taken?

SUMMARY

In this topic you learned that batteries are widely used as sources of direct-current. You were introduced to electrochemical action and the way it works in a cell, the cell itself, the type and parts of a cell, and how cells are connected together to form batteries. You learned the construction and maintenance of batteries and some of the safety precautions in handling and working with batteries. Several new terms were introduced in this topic. The following is a summary of the topic on batteries.

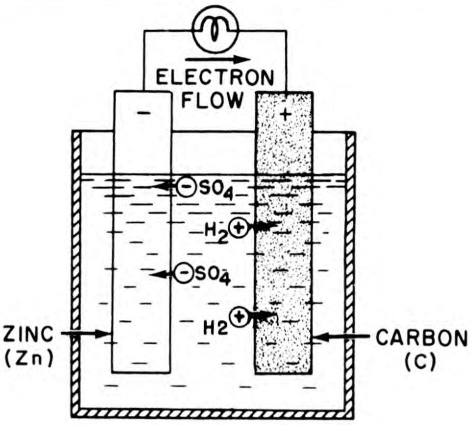
A31. At all times.

A32. Forty hours.

A33. No, a current must be passed through the battery.

A34. Reduce the charging rate.

A CELL is a device that transforms chemical energy into electrical energy. The cell has three parts, the electrodes, the electrolyte, and the container. There are two basic cells, primary and secondary.



THE ELECTRODES are the current conductors of the cell.

THE ELECTROLYTE is the solution that acts upon the electrodes.

THE CONTAINER holds the electrolyte and provides a means of mounting the electrodes.

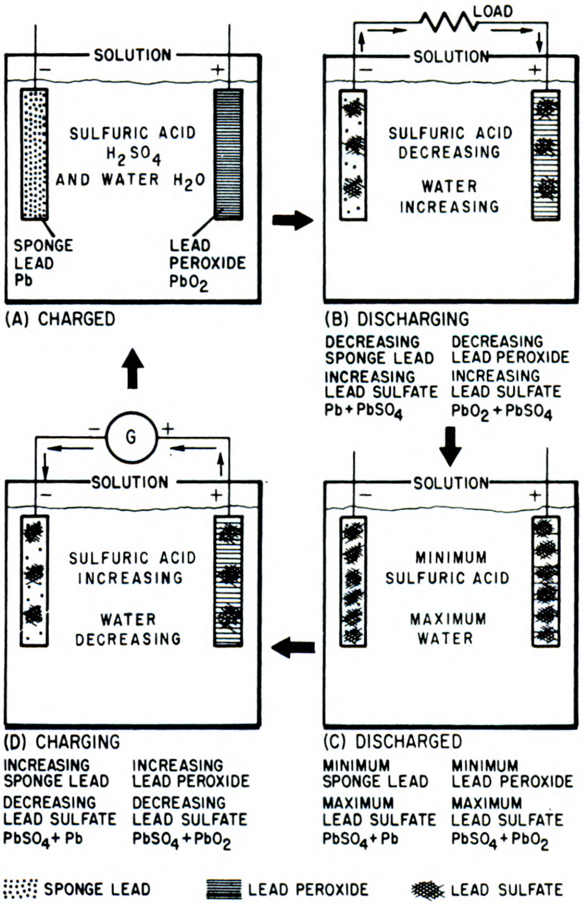
THE PRIMARY CELL is a cell in which the chemical action finally destroys one of the electrodes, usually the negative. The primary cell cannot be recharged.

THE SECONDARY CELL is a cell in which the chemical action alters the electrodes and electrolyte. The electrodes and electrolyte can be restored to their original condition by recharging the cell.

ELECTROCHEMICAL ACTION is the process of converting chemical energy into electrical energy.

THE ANODE is the positive electrode of a cell.

THE CATHODE is the negative electrode of a cell.


SOLUTION
−
+
SULFURIC ACID
H_2SO_4
AND WATER H_2O
SPONGE LEAD
Pb
LEAD PEROXIDE
PbO_2
LOAD
SULFURIC ACID DECREASING
WATER INCREASING
G
SULFURIC ACID INCREASING
WATER DECREASING
MINIMUM SULFURIC ACID
MAXIMUM WATER
SPONGE LEAD
LEAD PEROXIDE
LEAD SULFATE

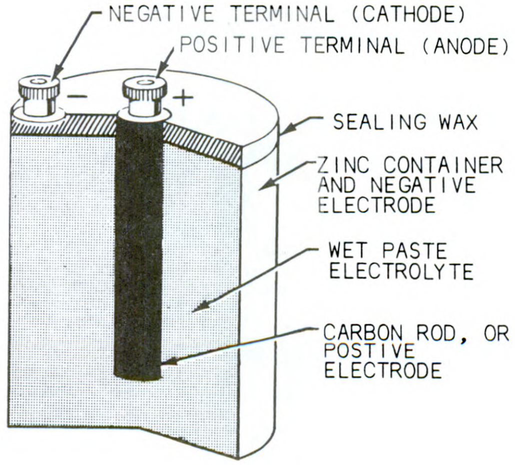
(A) CHARGED

(B) DISCHARGING
DECREASING SPONGE LEAD
DECREASING LEAD PEROXIDE
INCREASING LEAD SULFATE
INCREASING LEAD SULFATE
$Pb + PbSO_4$
$PbO_2 + PbSO_4$

(D) CHARGING
INCREASING SPONGE LEAD
INCREASING LEAD PEROXIDE
DECREASING LEAD SULFATE
DECREASING LEAD SULFATE
$PbSO_4 + Pb$
$PbSO_4 + PbO_2$

(C) DISCHARGED
MINIMUM SPONGE LEAD
MINIMUM LEAD PEROXIDE
MAXIMUM LEAD SULFATE
MAXIMUM LEAD SULFATE
$PbSO_4 + Pb$
$PbSO_4 + PbO_2$

PRIMARY CELL CHEMISTRY is the process in which electrons leaving the cathode to the load cause a positive charge which attracts negative ions from the electrolyte. The negative ions combine with the material of the cathode and form a substance such as lead-sulfate. Electrons from the load to the anode create a negative charge which attracts positive ions (hydrogen) from the electrolyte.

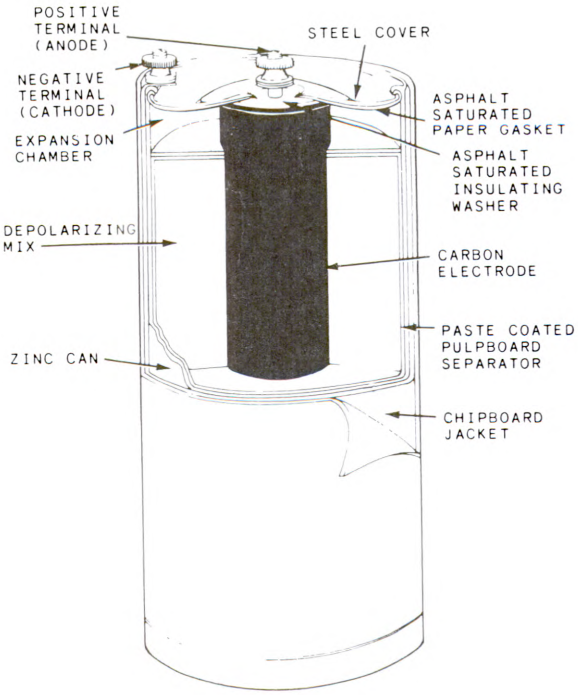

NEGATIVE TERMINAL (CATHODE)
POSITIVE TERMINAL (ANODE)
−
+
SEALING WAX
ZINC CONTAINER AND NEGATIVE ELECTRODE
WET PASTE ELECTROLYTE
CARBON ROD, OR POSTIVE ELECTRODE

SECONDARY CELL CHEMISTRY is the process in which the electrolyte acts upon and chemically changes both electrodes. This process also depletes the amount of active material in the electrolyte. A charging current applied to the cell reverses the process and restores the cell to its original condition.

POLARIZATION is the effect of hydrogen surrounding the anode of a cell which increases the internal resistance of the cell. Polarization can be prevented by venting the cell, adding a material rich in oxygen, or adding a material that will absorb hydrogen.

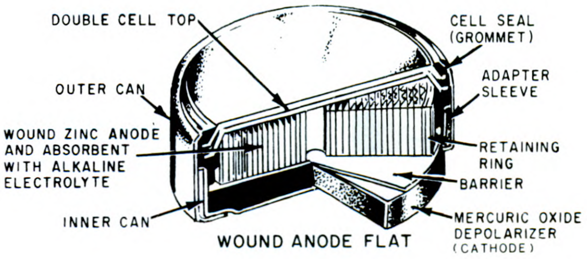
LOCAL ACTION is the continuation of current flow within the cell when there is no external load. It is caused by impurities in the electrode and can be prevented by the use of mercury amalgamated with the material of the electrode.

THE DRY CELL is the type commonly referred to as the "flashlight battery". Since the electrolyte is not in liquid form, but is a paste, the term dry cell is used. In most dry cells the case is the cathode.


POSITIVE TERMINAL (ANODE)
STEEL COVER
NEGATIVE TERMINAL (CATHODE)
ASPHALT SATURATED PAPER GASKET
EXPANSION CHAMBER
ASPHALT SATURATED INSULATING WASHER
DEPOLARIZING MIX
CARBON ELECTRODE
PASTE COATED PULPBOARD SEPARATOR
ZINC CAN
CHIPBOARD JACKET

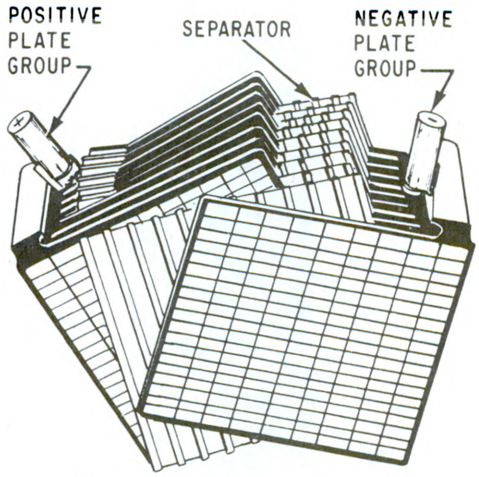
SHELF LIFE is the period the cell may be stored and still be useable.

MERCURY CELLS should never be shorted because of the danger of explosion.


DOUBLE CELL TOP
CELL SEAL (GROMMET)
OUTER CAN
ADAPTER SLEEVE
WOUND ZINC ANODE AND ABSORBENT WITH ALKALINE ELECTROLYTE
RETAINING RING
BARRIER
INNER CAN
WOUND ANODE FLAT
MERCURIC OXIDE DEPOLARIZER (CATHODE)

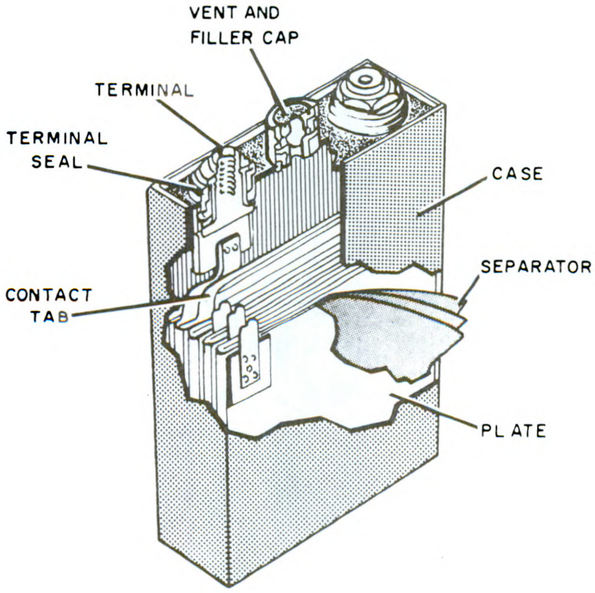
DRY CELLS are of many types, each having advantages and disadvantages. The type selected for use depends on such factors as cost, size, ease of replacement, and voltage or current needs.

THE LEAD-ACID CELL is the most widely used secondary cell. The lead-acid cell produces electricity by electrochemical action. The anode is lead perioxide, the cathode is sponge lead, and the electrolyte is sulfuric acid and water.


POSITIVE PLATE GROUP
SEPARATOR
NEGATIVE PLATE GROUP

CELL ELEMENT
PARTLY ASSEMBLED

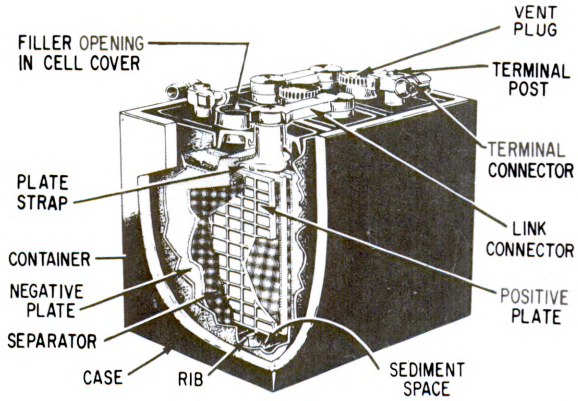
THE NICKEL-CADMIUM CELL, commonly called the NICAD, has the following advantages over the lead-acid cell; charges in a shorter period of time, delivers a larger amount of power, stays idle longer, and can be charged and discharged many times. The anode is nickel hydroxide, the cathode is cadmium hydroxide, and the electrolyte is potassium hydroxide and water.


VENT AND FILLER CAP
TERMINAL
TERMINAL SEAL
CASE
SEPARATOR
CONTACT TAB
PLATE

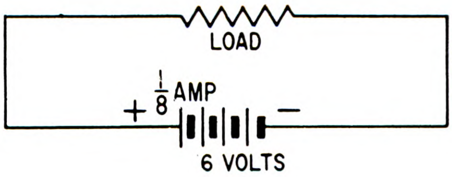
THE SILVER-ZINC CELL is used mostly for emergency equipment. It is light, small, and has a large power capacity for its size. The anode is silver oxide, the cathode is zinc, and the electrolyte is potassium hydroxide and water.

THE SILVER-CADMIUM CELL combines the better features of the nickel-cadmium and silver-zinc cells. The anode is silver-oxide, the cathode is cadmium hydroxide, and the electrolyte is potassium hydroxide.

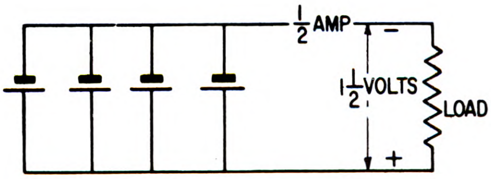
A BATTERY is a voltage source in a single container made from one or more cells. The cells can be combined in series, parallel, or series-parallel.


FILLER OPENING IN CELL COVER
VENT PLUG
TERMINAL POST
TERMINAL CONNECTOR
PLATE STRAP
LINK CONNECTOR
CONTAINER
NEGATIVE PLATE
POSITIVE PLATE
SEPARATOR
CASE
RIB
SEDIMENT SPACE

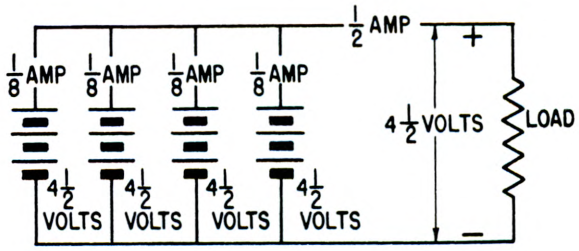
SERIES CONNECTED CELLS provide a higher voltage than a single cell, with no increase in current.


LOAD
$\frac{1}{8}$ AMP
+
−
6 VOLTS

PARALLEL CONNECTED CELLS provide a higher current than a single cell, with no increase in voltage.


$\frac{1}{2}$ AMP
−
$1\frac{1}{2}$ VOLTS
LOAD
+

SERIES-PARALLEL CONNECTED CELLS provide a higher voltage and a higher current than a single cell.



TYPES OF BATTERIES can be determined from nameplate data.

HYDROMETER provides the means to check the specific gravity of the electrolyte.

SAFETY PRECAUTIONS should always be followed when working with or around batteries.

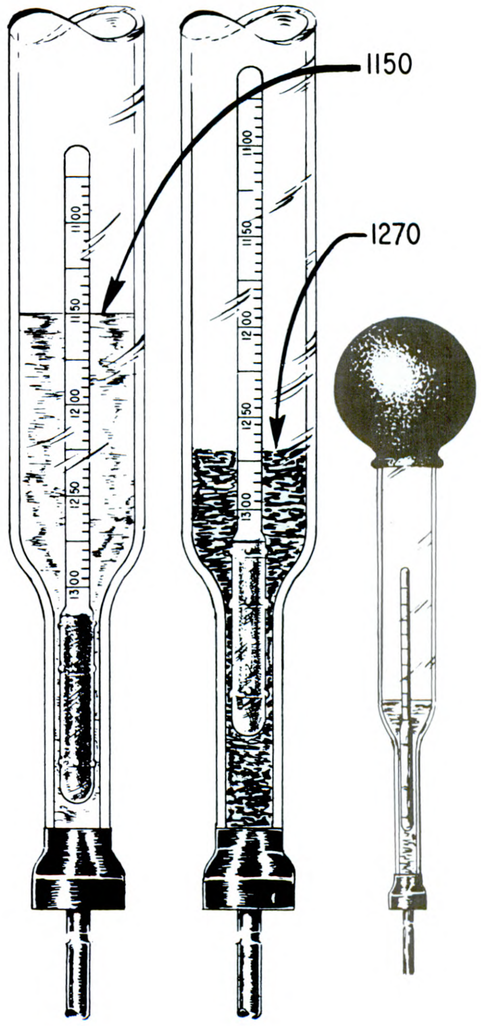
CAPACITY is an indication of the current supplying capability of the battery for a specific period of time; e.g., 400 ampere-hour.

RATING is the capacity of the battery for a specific rate of discharge. In most batteries the rating is given for a 20 hour discharge cycle; e.g., 20 amperes for 20 hours.

BATTERY CHARGE is the process of reversing the current flow through the battery to restore the battery to its original condition. The addition of active ingredient to the electrolyte will not recharge the battery. There are five types of charges:

1. Initial charge
2. Normal charge
3. Equalizing charge
4. Floating charge
5. Fast charge

GASSING is the production of hydrogen gas caused by a portion of the charge current breaking down the water in the electrolyte. Steady gassing is normal during the charging process. Violent gassing indicates that the charge rate is too high.



TOPIC 3

DIRECT CURRENT

LEARNING OBJECTIVES

Upon completing this topic you will be able to:

1. Identify the term schematic diagram and identify the components in a circuit from a simple schematic diagram.
2. State the equation for Ohm's law and describe the effects on current caused by changes in a circuit.
3. Given simple graphs of current versus power and voltage versus power, determine the value of circuit power for a given current and voltage.
4. Identify the term power and state three formulas for computing power.
5. Compute circuit and component power in series, parallel, and combination circuits.
6. Compute the efficiency of an electrical device.
7. Solve for unknown quantities of resistance, current, and voltage in a series circuit.
8. Describe how voltage polarities are assigned to the voltage drops across resistors when Kirchhoff's voltage law is used.
9. State the voltage at the reference point in a circuit.
10. Define open and short circuits and describe their effects on a circuit.
11. State the meaning of the term source resistance and describe its effect on a circuit.
12. Describe in terms of circuit values the circuit condition needed for maximum power transfer.
13. Compute efficiency of power transfer in a circuit.
14. Solve for unknown quantities of resistance, current, and voltage in a parallel circuit.
15. State the significance of the polarity assigned to a current when using Kirchhoff's current law.
16. State the meaning of the term equivalent resistance.
17. Compute resistance, current, voltage, and power in voltage dividers.
18. Describe the method by which a single voltage divider can provide both positive and negative voltages.
19. Recognize the safety precautions associated with the hazard of electrical shock.
20. Identify the first aid procedures for a victim of electrical shock.

INTRODUCTION

The material covered in this topic contains many new terms that are explained as you progress through the material. The basic d.c. circuit is the easiest to understand, so the topic begins with the basic circuit and from there works into the basic schematic diagram of that circuit. The schematic diagram is used in all your future work in electricity and electronics. It is very important that you become familiar with the symbols that are used.

This topic also explains how to determine the total resistance, current, voltage, and power in a series, parallel, or combination circuit through the use of Ohm's and Kirchhoff's laws. The voltage divider network, series, parallel, and series-parallel practice problem circuits will be used for practical examples of what you have learned.

THE BASIC ELECTRIC CIRCUIT

The flashlight is an example of a basic electric circuit. It contains a source of electrical energy (the dry cells in the flashlight), a load (the bulb) which changes the electrical energy into a more useful form of energy (light), and a switch to control the energy delivered to the load.

Before you study a schematic representation of the flashlight, it is necessary to define certain terms. The LOAD is any device through which an electrical current flows and which changes this electrical energy into a more useful form. Some common examples of loads are a lightbulb, which changes electrical energy to light energy, an electric motor, which changes electrical energy into mechanical energy; and the speaker into a radio, which changes electrical energy into sound. The SOURCE is the device which furnishes the electrical energy used by the load. It may consist of a simple dry cell (as in a flashlight), a storage battery (as in an automobile), or a power supply (such as a battery charger). The SWITCH, which permits control of the electrical device, interrupts the current delivered to the load.

SCHEMATIC REPRESENTATION

The technician's main aid in troubleshooting a circuit in a piece of equipment is the SCHEMATIC DIAGRAM. The schematic diagram is a "picture" of the circuit that uses symbols to represent the various circuit components; physically large or complex circuits can be shown on a relatively small diagram. Before studying the basic schematic, look at figure 3-1. This figure shows the symbols that are used in this topic. These, and others like them, are referred to and used throughout the study of electricity and electronics.

The schematic in figure 3-2 represents a flashlight. Part A of the figure shows the flashlight in the off or deenergized state. The switch (S1) is open. There is no complete path for current (I) through the circuit, and the bulb (DS1) does not light. In figure 3-2(B), switch S1 is closed. Current flows in the direction of the arrows from the negative terminal of the battery (BAT), through the switch (S1), through the lamp (DS1), and back to the positive terminal of the battery. With the switch closed the path for current is complete. Current will continue to flow until the switch (S1) is moved to the open position or the battery is completely discharged.

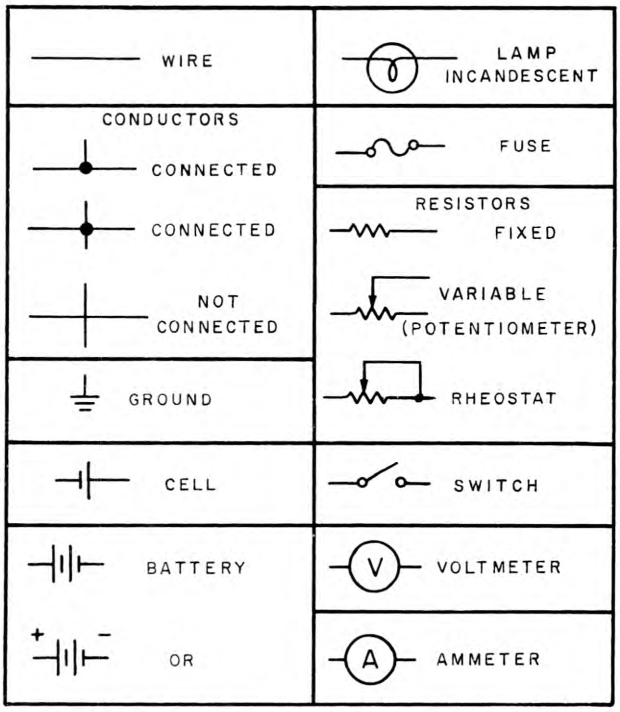
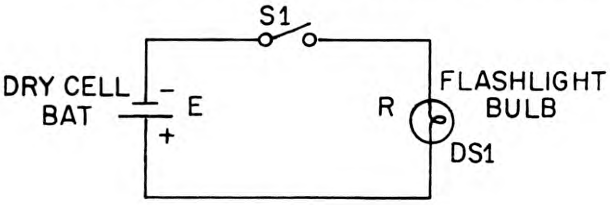
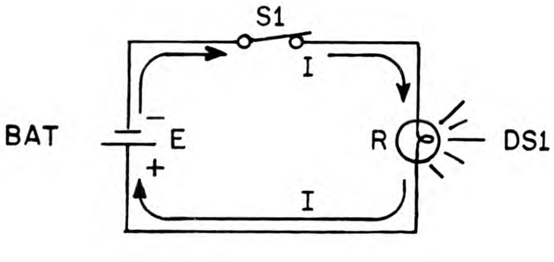

WIRE
LAMP INCANDESCENT
CONDUCTORS
CONNECTED
CONNECTED
NOT CONNECTED
FUSE
RESISTORS
FIXED
VARIABLE (POTENTIOMETER)
GROUND
RHEOSTAT
CELL
SWITCH
BATTERY
VOLTMETER
V
+
-
OR
AMMETER
A

Figure 3-1.—Symbols commonly used in electricity.


S1
DRY CELL
BAT
-
+
E
R
FLASHLIGHT BULB
DS1

(A) DEENERGIZED


S1
I
BAT
-
+
E
R
DS1
I

(B) ENERGIZED

A. Deenergized.
B. Energized.
Figure 3-2.—Basic flashlight schematic.

Q1. **In figure 3-2, what part of the circuit is the (a) load and (b) source?**

Q2. **What happens to the path for current when S1 is open as shown in figure 3-2(A)?**

Q3. **What is the name given to the "picture" of a circuit such as the one shown in figure 3-2?**

OHM'S LAW

In the early part of the 19th century George Simon Ohm proved by experiment that a precise relationship exists between current, voltage, and resistance. This relationship is called Ohm's Law and is stated as follows:

The current in a circuit is DIRECTLY proportional to the applied voltage and INVERSELY proportional to the circuit resistance. Ohm's Law may be expressed as an equation:

$$I = \frac{E}{R}$$

Where: I = current in amperes

E = voltage in volts

R = resistance in ohms

As stated in Ohm's law, current is inversely proportional to resistance. This means, as the resistance in a circuit increases, the current decreases proportionately.

In the equation $I = \frac{E}{R}$, if any two quantities are known, the third one can be determined.

A1. **(a) DS1, the flashlight bulb**
(b) BAT, the dry cell

A2. **The path for current is incomplete; or, there is no path for current with S1 open.**

A3. **A schematic diagram**

Refer to figure 3-2(B), the schematic of the flashlight. If the battery (BAT) supplies a voltage of 1.5 volts and the lamp (DS1) has a resistance of 5 ohms, then the current in the circuit can be determined. Using this equation and substituting values:

$$I = \frac{E}{R} = \frac{1.5 \text{ volts}}{5 \text{ ohms}} = .3 \text{ ampere}$$

If the flashlight were a two-cell flashlight, we would have twice the voltage, or 3.0 volts, applied to the circuit. Using this voltage in the equation:

$$I = \frac{3.0 \text{ volts}}{5 \text{ ohms}} = .6 \text{ ampere}$$

You can see that the current has doubled as the voltage has doubled. This demonstrates that the current is directly proportional to the applied voltage.

If the value of resistance of the lamp is doubled, the equation will be:

$$I = \frac{E}{R} = \frac{3.0 \text{ volts}}{10 \text{ ohms}} = .3 \text{ ampere}$$

The current has been reduced to one-half of the value of the previous equation, or .3 ampere. This demonstrates that the current is inversely proportional to the resistance. Doubling the value of the resistance of the load reduces circuit current value to one-half of its former value.

APPLICATION OF OHM'S LAW

By using Ohm's law, you are able to find the resistance of a circuit, knowing only the voltage and the current in the circuit.

In any equation, if all the variables (parameters) are known except one, that unknown can be found. For example, using Ohm's law, if current (I) and voltage (E) are known, resistance (R) the only parameter not known, can be determined:

1. Basic formula: $I = \frac{E}{R}$

2. Remove the divisor by multiplying both sides by R:

$$R \times I = \frac{E}{\cancel{R}} \times \frac{\cancel{R}}{1}$$

3. Result of step 2: $R \times I = E$

4. To get R alone (on one side of the equation) divide both sides by I: $\frac{R\cancel{I}}{\cancel{I}} = \frac{E}{I}$

5. The basic formula, transposed for R, is:

$$R = \frac{E}{I}$$

Refer to figure 3-3 where E equals 10 volts and I equals 1 ampere. Solve for R, using the equation just explained.

Given: E = 10 volts

I = 1 ampere

Solution:

$$R = \frac{E}{I}$$

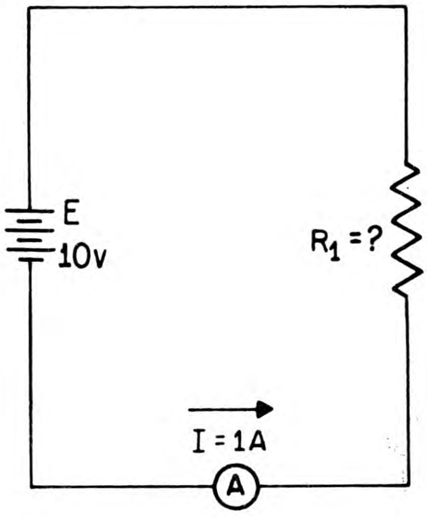


Figure 3-3.—Determining resistance in a basic circuit.

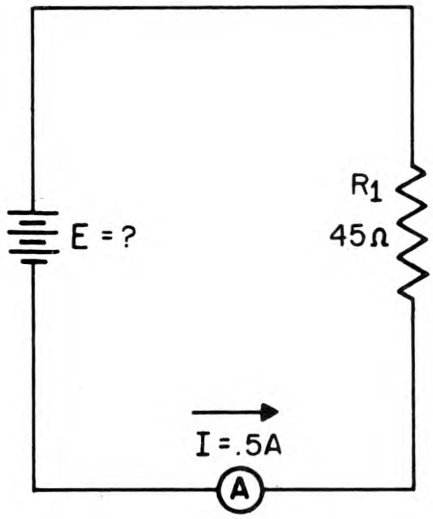


Figure 3-4.—Determining voltage in a basic circuit.

Insert the values of the known quantities:

$$R = \frac{10 \text{ volts}}{1 \text{ ampere}}$$

$$R = 10 \text{ ohms}$$

The basic formula can also be used to solve for E.

Take the basic formula: $I = \frac{E}{R}$

multiply both sides by R: $I \times R = \frac{E}{\cancel{R}} \times \frac{\cancel{R}}{1}$

Results: $E = I \times R$

This equation can be used to find the voltage for the circuit shown in figure 3-4.

Given: $I = .5$ ampere

$R = 45$ ohms

Solution:

$E = I \times R$

$E = .5 \text{ ampere} \times 45 \text{ ohms}$

$E = 22.5 \text{ volts}$

The Ohm's law equation and its various forms may be obtained readily with the aid of figure 3-5. The circle containing E, I, and R is divided into two parts, with E above the line and with I and R below the line. To determine the unknown quantity, first cover that quantity with a finger. The position of the uncovered letters in the circle will indicate the mathematical operation to be performed. For example, to find I, cover I with a finger. The uncovered letters indicate that E is to be divided by R, or $I = \frac{E}{R}$. To find the formula for E, cover E with your finger. The result indicates that I is to be multiplied by R, or E = IR. To find the formula for R, cover R. The result indicates that E is to be divided by I, or $R = \frac{E}{I}$.

You are cautioned not to rely wholly on the use of this diagram when you transpose the Ohm's law formulas. The diagram should be used to supplement your knowledge of the algebraic method. Algebra is a basic tool in the solution of electrical problems.

Q4. According the Ohm's law, what happens to circuit current if the applied voltage (a) increases, (b) decreases?

A4. **(a) Current increases**

(b) Current decreases

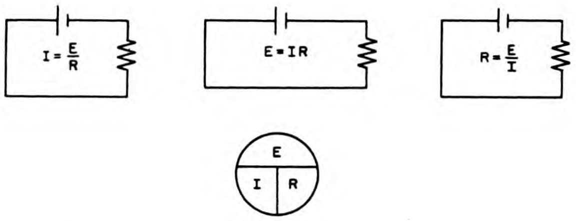


Figure 3-5.—Ohm's law in diagram form.

Q5. **According to Ohm's law, what happens to circuit current if circuit resistance (a) increases, (b) decreases?**

Q6. **What is the equation used to find circuit resistance if voltage and current values are known?**

GRAPHICAL ANALYSIS OF THE BASIC CIRCUIT

One of the most valuable methods of analyzing a circuit is by constructing a graph. No other method provides a more convenient or more rapid way to observe the characteristics of an electrical device.

The first step in constructing a graph is to obtain a table of data. The information in the table can be obtained by taking measurements on the circuit under examination, or can be obtained theoretically through a series of Ohm's law computations. The latter method is used here.

Since there are three variables (E, I, and R) to be analyzed, there are three distinct graphs that may be constructed.

To construct any graph of electrical quantities, it is standard practice to vary one quantity in a specified way and note the changes which occur in a second quantity. The quantity which is intentionally varied is called the independent variable and is plotted on the horizontal axis. The horizontal axis is known as the X-AXIS. The second quantity, which varies as a result of changes in the first quantity, is called the dependent variable and is plotted on the vertical, or Y-AXIS. Any other quantities involved are held constant.

For example, in the circuit shown in figure 3-6 if the resistance was held at 10 ohms and

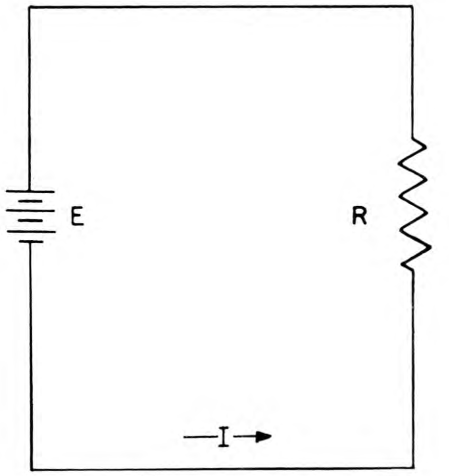
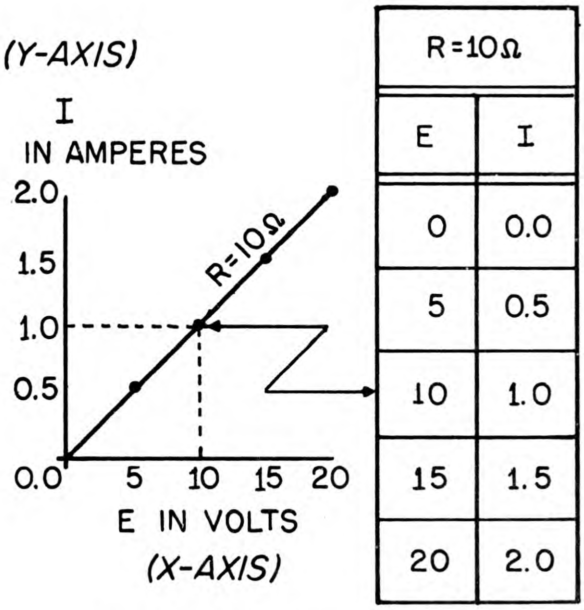


Figure 3-6.—Three variables in a basic circuit.



R=10Ω	
E	I
0	0.0
5	0.5
10	1.0
15	1.5
20	2.0

Figure 3-7.—Volt-ampere characteristic.

the voltage was varied, the resulting changes in current could then be graphed. The resistance is the constant, the voltage is the independent variable, and the current is the dependent variable.

Figure 3-7 shows the graph and a table of values. This table shows R held constant at 10 ohms as E is varied from 0 to 20 volts in 5-volt steps. Through the use of Ohm's law, you can calculate the value of current for each value of voltage shown in the table. When the table is complete, the information it contains can be used to construct the graph shown in figure 3-7. For example, when the voltage applied to the 10-ohm resistor is 10 volts, the current is 1 ampere. These values of current and voltage determine a point on the graph. When all five points have been plotted, a smooth curve is drawn through the points.

Through the use of this curve, the value of current through the resistor can be quickly determined for any value of voltage between 0 and 20 volts.

Since the curve is a straight line, it shows that equal changes of voltage across the resistor produce equal changes in current through the resistor. This fact illustrates an important characteristic of the basic law—the current varies directly with the applied voltage when the resistance is held constant.

When the voltage across a load is held constant, the current depends solely upon the resistance of the load. For example, figure 3-8 shows a graph with the voltage held constant at 12 volts. The independent variable is the resistance which is varied from 2 ohms to 12 ohms. The current is the dependent variable. Values for current can be calculated as:

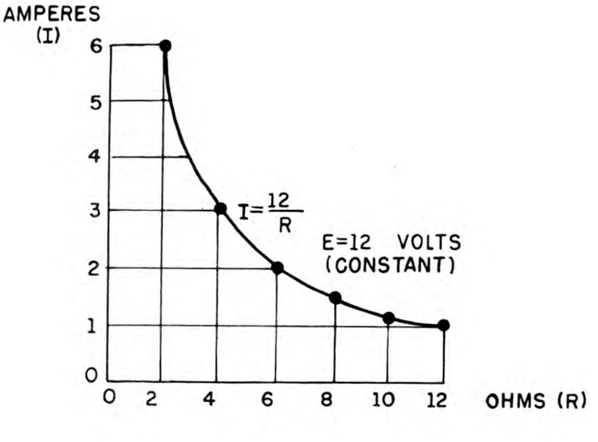


Figure 3-8.—Relation between current and resistance.

Given:

$E = 12$ volts

$R = 2$ ohms to 12 ohms

Solution:

$$I = \frac{E}{R}$$

$$I = \frac{12 \text{ volts}}{12 \text{ ohms}} = 1 \text{ ampere}$$

$$I = \frac{12 \text{ volts}}{10 \text{ ohms}} = 1.2 \text{ amperes}$$

$$I = \frac{12 \text{ volts}}{8 \text{ ohms}} = 1.5 \text{ amperes}$$

$$I = \frac{12 \text{ volts}}{6 \text{ ohms}} = 2 \text{ amperes}$$

This process can be continued for any value of resistance. You can see that as the resistance is halved, the current is doubled; when the resistance is doubled, the current is halved.

This illustrates another important characteristic of Ohm's law—current varies inversely with resistance when the applied voltage is held constant.

Q7. Using the graph in figure 3-7, what is the approximate value of current when the voltage is 12.5 volts?

Q8. Using the graph in figure 3-8, what is the approximate value of current when the resistance is 3 ohms?

POWER

Power, whether electrical or mechanical, pertains to the rate at which work is being done. Work is done whenever a force causes motion. When a mechanical force is used to lift or move

A5. (a) Current decreases

(b) Current increases

A6. $R = \frac{E}{I}$

A7. 1.25 amperes

A8. 4 amperes

---

a weight, work is done. However, force exerted WITHOUT causing motion, such as the force of a compressed spring acting between two fixed objects, does not constitute work.

Previously, it was shown that voltage is an electrical force, and that voltage forces current to flow in a closed circuit. However, when voltage exists but current does not flow because the circuit is open, no work is done. This is similar to the spring under tension that produced no motion. When voltage causes electrons to move, work is done. The instantaneous RATE at which this work is done is called the electric power rate, and is measured in WATTS.

A total amount of work may be done in different lengths of time. For example, a given number of electrons may be moved from one point to another in 1 second or in 1 hour, depending on the RATE at which they are moved. In both cases, total work done is the same. However, when the work is done in a short time, the wattage, or INSTANTANEOUS POWER RATE, is greater than when the same amount of work is done over a longer period of time.

As stated, the basic unit of power is the watt. Power in watts is equal to the voltage across a circuit multiplied by current through the circuit. This represents the rate at any given instant at which work is being done. The symbol P indicates electrical power. Thus, the basic power formula is $P = E \times I$. Where E is voltage and I is current in the circuit. The amount of power changes when either voltage or current, or both voltage and current, are caused to change.

In practice, the ONLY factors that can be changed are voltage and resistance. In explaining the different forms that formulas may take, current is sometimes presented as a quantity that is changed. Remember if current is changed it is because either voltage or resistance has been changed.

Figure 3-9 shows a basic circuit using a source of power that can be varied from 0 to 8 volts and a graph that indicates the relationship between voltage and power.

The resistance of this circuit is 2 ohms; this value does not change. Voltage (E) is increased (by increasing the voltage source), in steps of 1 volt, from 0 volts to 8 volts. By applying Ohm's law, the current (I) is determined for each step of voltage. For instance, when E is 1 volt, the current is:

$$I = \frac{E}{R}$$

$$I = \frac{1 \text{ volt}}{2 \text{ ohms}}$$

$$I = 0.5 \text{ ampere}$$

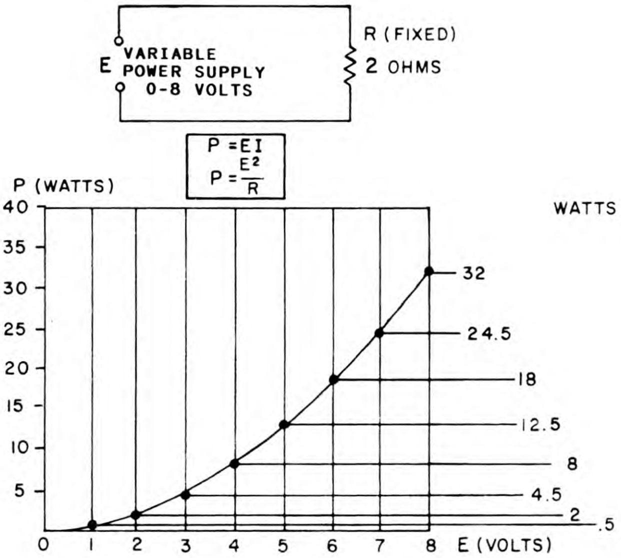


Figure 3-9.—Graph of power related to changing voltage.

Power (P), in watts, is determined by applying the basic power formula:

$$P = E \times I$$

$$P = 1 \text{ volt} \times 0.5 \text{ ampere}$$

$$P = 0.5 \text{ watt}$$

When E is increased to 2 volts:

$$I = \frac{E}{R}$$

$$I = \frac{2 \text{ volts}}{2 \text{ ohms}}$$

$$I = 1 \text{ ampere}$$

and

$$P = E \times I$$

$$P = 2 \text{ volts} \times 1 \text{ ampere}$$

$$P = 2 \text{ watts}$$

When E is increased to 3 volts:

$$I = \frac{E}{R}$$

$$I = \frac{3 \text{ volts}}{2 \text{ ohms}}$$

$$I = 1.5 \text{ amperes}$$

and

$$P = E \times I$$

$$P = 3 \text{ volts} \times 1.5 \text{ amperes}$$

$$P = 4.5 \text{ watts}$$

You should notice that when the voltage was increased to 2 volts, the power increased from .5 watts to 2 watts or 4 times. When the voltage increased to 3 volts, the power increased to 4.5 watts or 9 times. This shows that if the resistance in a circuit is held constant, the power varies directly with the SQUARE OF THE VOLTAGE.

Another way of proving that power varies as the square of the voltage when resistance is held constant is:

Since $I = \frac{E}{R}$

By substitution in: $P = E \times I$

You get: $P = E \times \frac{E}{R}$

Or: $P = \frac{E \times E}{R}$

Therefore: $P = \frac{E^2}{R}$

Another important relationship may be seen by studying figure 3-10. Thus far, power has been calculated with voltage and current ($P = E \times I$), and with voltage and resistance ($P = \frac{E^2}{R}$). Referring to figure 3-10, note that

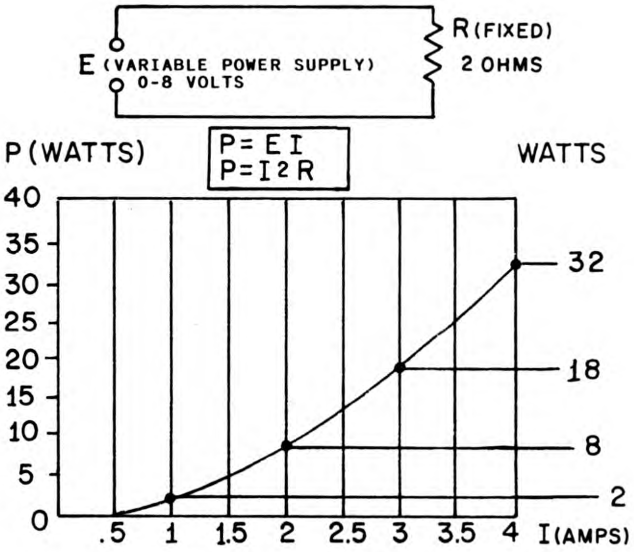


Figure 3-10.—Graph of power related to changing current.

power also varies as the square of current just as it does with voltage. Thus, another formula for power, with current and resistance as its factors, is $P = I^2 R$. This can be proved by:

Since: $E = I \times R$

By substitution in: $P = E \times I$

You get: $P = I \times R \times I$

Or: $P = I \times I \times R$

Therefore: $P = I^2 R$

Up to this point, four of the most important electrical quantities have been discussed. These are voltage (E), current (I), resistance (R), and power (P). You must understand the relationships which exist among these quantities because they are used throughout your study of electricity. In the preceding paragraphs, P was expressed in terms of alternate pairs of the other three basic quantities E, I, and R. In practice, you should be able to express any one of these quantities in terms of any two of the others.

Figure 3-11 is a summary of 12 basic formulas you should know. The four quantities E, I, R, and P are at the center of the figure. Adjacent to each quantity are three segments. Note that in each segment, the basic quantity is expressed in terms of two other basic quantities, and no two segments are alike.

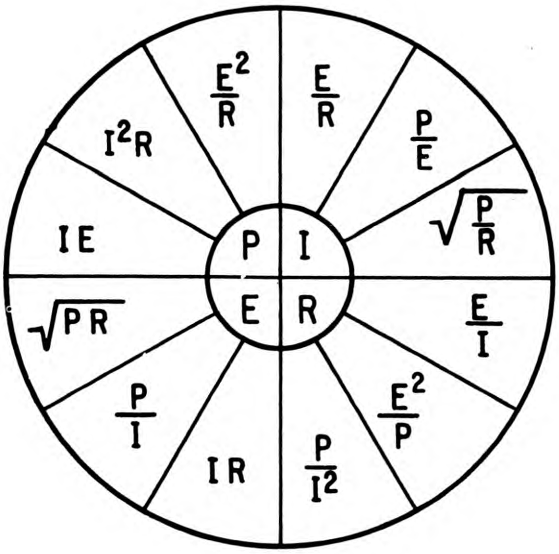


Figure 3-11.—Summary of basic formulas.

For example, the formula wheel in figure 3-11 could be used to find the formula to solve the following problem:

A circuit has a voltage source that delivers 6 volts and the circuit uses 3 watts of power. What is the resistance of the load?

Since R is the quantity you have been asked to find, look in the section of the wheel that has R in the center. The segment $\frac{E^2}{P}$ contains the quantities you have been given. The formula you would use is $R = \frac{E^2}{P}$. The problem can now be solved.

Given: $E = 6$ volts

$P = 3$ watts

Solution: $R = \frac{E^2}{P}$

$$\frac{(6 \text{ volts})^2}{3 \text{ watts}}$$

$$R = \frac{36}{3} = 12 \text{ ohms}$$

Q9. What is the term applied to the rate at which a mechanical or electrical force causes motion?

Q10. How can the amount of current be changed in a circuit?

Q11. What are the three formulas for electrical power?

POWER RATING

Electrical components are often given a power rating. The power rating, in watts, indicates the rate at which the device converts electrical energy into another form of energy, such as light, heat, or motion. An example of such a rating is noted when comparing a 150-watt lamp to a 100-watt lamp. The higher wattage rating of the 150-watt lamp indicates it is capable of converting more electrical energy into light energy than the lamp of the lower rating. Other common examples of devices with power ratings are soldering irons and small electric motors.

In some electrical devices the wattage rating indicates the maximum power the device is designed to use rather than the normal operating power. A 150-watt lamp, for example, uses 150 watts when operated at the specified voltage printed on the bulb. In contrast, a device such as a resistor is not normally given a voltage or a current rating. A resistor is given a power rating in watts and can be operated at any combination of voltage and current as long as the power rating is not exceeded. In most circuits, the actual power used by a resistor is considerably less than the power rating of the resistor because a 50% safety factor is used. For example, if a resistor normally used 2 watts of power, a resistor with a power rating of 3 watts would be used.

Resistors of the same resistance value are available in different wattage values. Carbon resistors, for example, are commonly made in wattage ratings of 1/8, 1/4, 1/2, 1, and 2 watts. The larger the physical size of a carbon resistor the higher the wattage rating. This is true because a larger surface area of material radiates a greater amount of heat more easily.

When resistors with wattage ratings greater than 5 watts are needed, wirewound resistors are used. Wirewound resistors are made in values between 5 and 200 watts. Special types of wirewound resistors are used for power in excess of 200 watts.

As with other electrical quantities, prefixes may be attached to the word watt when expressing very large or very small amounts of power. Some of the more common of these are the kilowatt (1000 watts), the megawatt (1,000,000 watts), and the milliwatt (1/1,000 of a watt).

Q12. What is the current in a circuit with 5 ohms of resistance that uses 180 watts of power? (refer to figure 3-12)

Q13. What type of resistor should be used in the circuit described in question 12?

Q14. What is the power used in a circuit that has 10 amperes of current through a 10 ohm resistor?

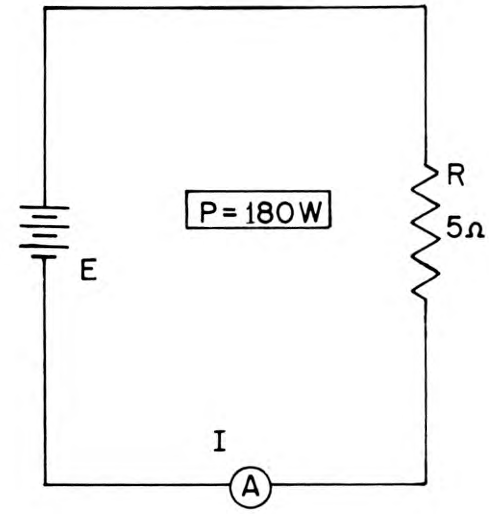


Figure 3-12.—Circuit for computing electrical quantities.

POWER CONVERSION AND EFFICIENCY

The term power consumption is common in the electrical field. It is applied to the use of power in the same sense that gasoline consumption is applied to the use of fuel in an automobile.

Another common term is power conversion. Power is used by electrical devices and is converted from one form of energy to another. An electrical motor converts electrical energy to mechanical energy. An electric light bulb converts electrical energy into light energy and an electric range converts electrical energy into heat energy. Power used by electrical devices is measured in watt-hours. This practical unit of electrical energy is equal to 1 watt of power used continuously for 1 hour. The term kilowatt hour (kWh) is used more extensively on a daily basis and is equal to 1000 watt-hours.

The EFFICIENCY of an electrical device is the ratio of power converted to useful energy divided by the power consumed by the device. This number will always be less than one (1.00) because of the losses in any electrical device. If a device has an efficiency rating of .95, it effectively transforms 95 watts into useful energy for every 100 watts of input power. The

A9. **Power**

A10. **By changing the circuit resistance or the voltage of the power source.**

A11. $\mathbf{P = E \times I, P = \frac{E^2}{R}, P = I^2 R}$

A12. **6 amperes**

A13. **A wirewound resistor**

A14. **1 kilowatt**

---

other 5 watts are lost to heat, or other losses which cannot be used.

Calculating the amount of power converted by an electrical device is a simple matter. You need to know the length of time the device is operated and the input power or horsepower rating. Horsepower, a unit of work, is often found as a rating on electrical motors. One horsepower is equal to 746 watts. Example: A 3/4 hp motor operates 8 hours a day. How much power is converted by the motor per month? How many kWh does this represent?

Given: $t = 8 \text{ hrs} \times 30 \text{ days}$

$P = 3/4 \text{ hp}$

Solution: Convert horsepower to watts

$P = \text{hp} \times 746 \text{ watts}$

$P = 3/4 \times 746 \text{ watts}$

$P = 559 \text{ watts}$

Convert watts to watt-hours

$P = \text{work} \times \text{time}$

$P = 559 \text{ watts} \times 8 \times 30$

$P = 134{,}000 \text{ watt-hours per month}$

(NOTE: These figures are rounded to the nearest 1000.)

To convert to kWh

$$P = \frac{\text{Power in watt-hours}}{1000}$$

$$P = \frac{134{,}000 \text{ watt-hours}}{1000}$$

$$P = 134 \text{ kWh}$$

If the motor actually uses 137 kWh per month, what is the efficiency of the motor?

Given: Power converted = 134 kWh per month
Power used = 137 kWh per month

Solution: $$\text{EFF} = \frac{\text{Power converted}}{\text{Power used}}$$

$$\text{EFF} = \frac{134 \text{ kWh per month}}{137 \text{ kWh per month}}$$

$$\text{EFF} = .978 \text{ (Rounded to three figures)}$$

Q15. **How much power is converted by a 1 horsepower motor in 12 hours?**

Q16. **What is the efficiency of the motor if it actually uses 9.5 kWh in 12 hours?**

SERIES D.C. CIRCUITS

When two unequal charges are connected by a conductor, a complete pathway for current exists. An electric circuit is a complete conducting pathway. It consists not only of the conductor, but also includes the path through the voltage source. Inside the voltage source current flows from the positive terminal, through the source, emerging at the negative terminal.

SERIES CIRCUIT CHARACTERISTICS

A SERIES CIRCUIT is defined as a circuit that contains only ONE PATH for current flow. To compare the basic circuit that has been discussed and a more complex series circuit, figure 3-13 shows two circuits. The basic circuit has only one lamp and the series circuit has three lamps connected in series.

Resistance in a Series Circuit

Referring to figure 3-13, the current in a series circuit must flow through each lamp to complete the electrical path in the circuit. Each additional lamp offers added resistance. In a series circuit, THE TOTAL CIRCUIT RESISTANCE (R_T) IS EQUAL TO THE SUM OF THE INDIVIDUAL RESISTANCES.

As an equation: $R_T = R_1 + R_2 + R_3 + \ldots R_n$

NOTE: The subscript n denotes any number of additional resistances that might be in the equation.

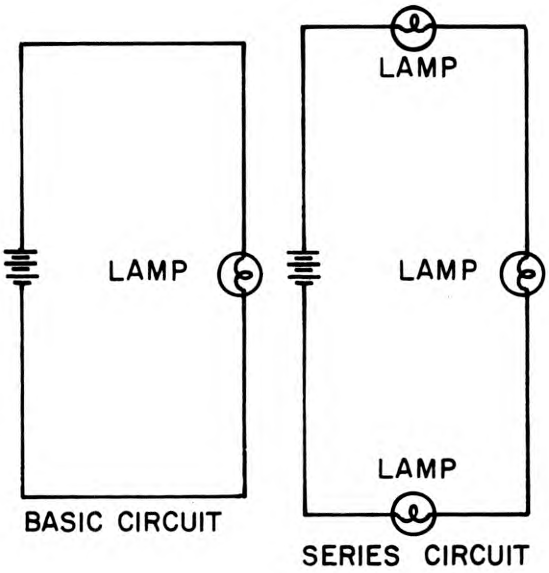


Figure 3-13.—Comparison of basic and series circuits.

Example: In figure 3-14 a series circuit consisting of three resistors; one of 10 ohms, one of 15 ohms, and one of 30 ohms; is shown. A voltage source provides 110 volts. What is the total resistance?

Given:

R_1 = 10 ohms

R_2 = 15 ohms

R_3 = 30 ohms

Solution:

$R_T = R_1 + R_2 + R_3$

R_T = 10 ohms + 15 ohms + 30 ohms

R_T = 55 ohms

In some circuit applications, the total resistance is known and the value of one of the circuit resistors has to be determined. The equation $R_T = R_1 + R_2 + R_3$ can be transposed to solve for the value of the unknown resistance.

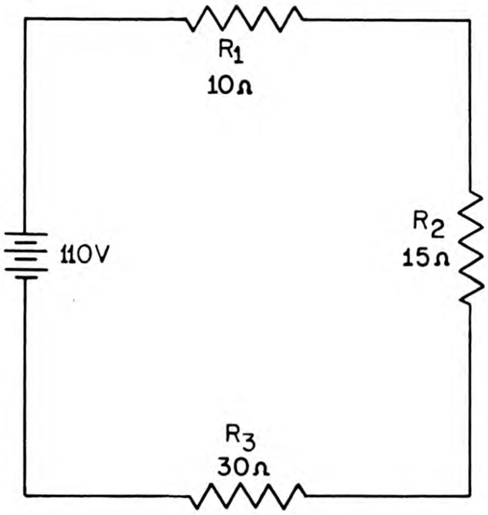


Figure 3-14.—Solving for total resistance in a series circuit.

A15. 8,952 watt hours or 8.952 kWh

A16. .942 (rounded to 3 places)

Example: In figure 3-15 the total resistance of a circuit containing three resistors is 40 ohms. Two of the circuit resistors are 10 ohms each. Calculate the value of the third resistor (R_3).

Given: R_T = 40 ohms

R_1 = 10 ohms

R_2 = 10 ohms

Solution: $R_T = R_1 + R_2 + R_3$

(Subtract $R_1 + R_2$ from both sides of the equation)

$R_T - R_1 - R_2 = R_3$

$R_3 = R_T - R_1 - R_2$

R_3 = 40 ohms - 10 ohms - 10 ohms

R_3 = 40 ohms - 20 ohms

R_3 = 20 ohms

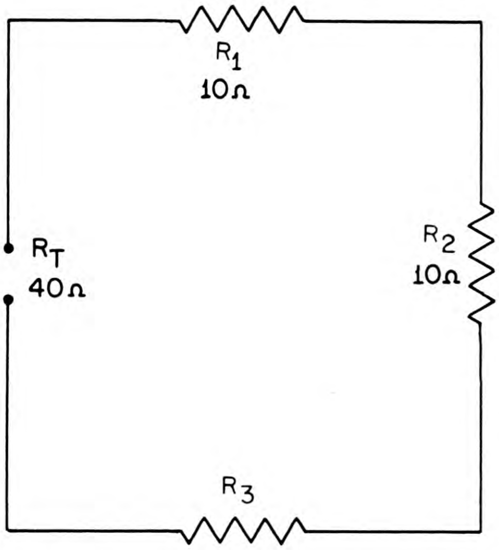


Figure 3-15.—Calculating the value of one resistance in a series circuit.

Current in a Series Circuit

Since there is only one path for current in a series circuit, the same current must flow through each component of the circuit. To determine the current in a series circuit, only the current through one of the components need be known.

The fact that the same current flows through each component of a series circuit can be verified by inserting meters into the circuit at various points, as shown in figure 3-16. If this were done, each meter would be found to indicate the same value of current.

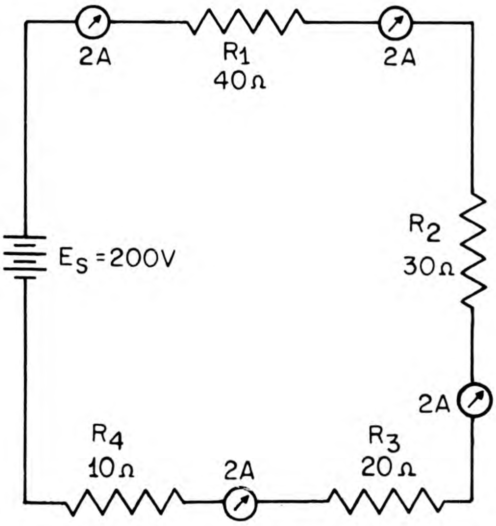


Figure 3-16.—Current in a series circuit.

Voltage in a Series Circuit

The voltage dropped across the resistor in a circuit consisting of a single resistor and a voltage source is the total voltage across the circuit and is equal to the applied voltage. The total voltage across a series circuit that consists of more than one resistor is also equal to the applied voltage, but consists of the sum of the individual resistor voltage drops. In any series circuit, the SUM of the resistor voltage drops must equal the source voltage. This statement can be proven by an examination of the circuit shown in figure 3-17. In this circuit a source potential (E_T) of 20 volts is dropped across a series circuit consisting of two 5-ohm resistors. The total resistance of the circuit (R_T) is equal to the sum of the two individual resistances, or 10 ohms. Using Ohm's law the circuit current may be calculated as follows:

Given: E_T = 20 volts

R_T = 10 ohms

Solution: $I_T = \frac{E_T}{R_T}$

$$I_T = \frac{20 \text{ volts}}{10 \text{ ohms}}$$

I_T = 2 amperes

Since the value of the resistors is known to be 5 ohms each, and the current through the resistors is known to be 2 amperes, the voltage drops across the resistors can be calculated. The voltage (E_1) across R_1 is therefore:

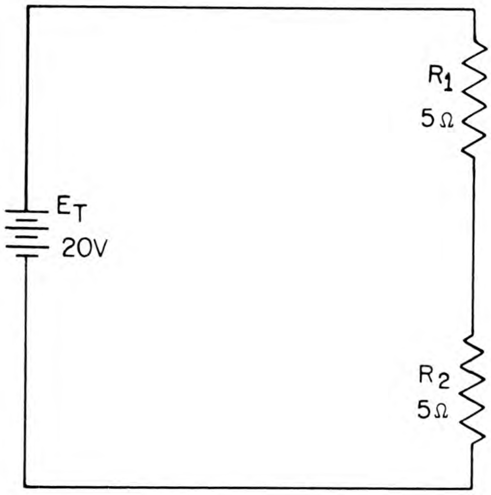


Figure 3-17.—Calculating individual voltage drops in a series circuit.

Given: I_1 = 2 amperes

R_1 = 5 ohms

Solution: $E_1 = I_1 \times R_1$

E_1 = 2 amperes x 5 ohms

E_1 = 10 volts

By inspecting the circuit, you can see that R_2 is the same ohmic value as R_1 and carries the same current. The voltage drop across R_2 is therefore also equal to 10 volts. Adding these two 10-volts drops together gives a total drop of 20 volts, exactly equal to the applied voltage. For a series circuit then:

$$E_T = E_1 + E_2 + E_3 + \ldots E_n$$

Example: A series circuit consists of three resistors having values of 20 ohms, 30 ohms, and 50 ohms, respectively. Find the applied voltage if the current through the 30 ohm resistor is 2 amps. (The abbreviation amp is commonly used for ampere.)

To solve the problem, a circuit diagram is first drawn and labeled (fig 3-18).

Given:

R_1 = 20 ohms

R_2 = 30 ohms

R_3 = 50 ohms

I = 2 amps

Solution:

$E_T = E_1 + E_2 + E_3$

$E_1 = R_1 \times I_1$ (I_1 = The current through resistor R_1.)

$E_2 = R_2 \times I_2$

$E_3 = R_3 \times I_3$

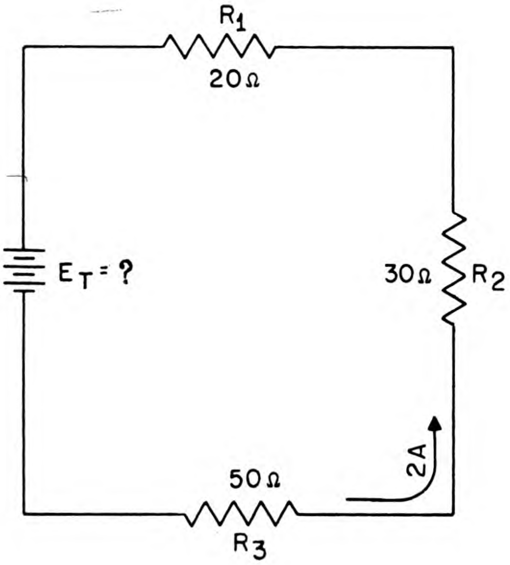


Figure 3-18.—Solving for applied voltage in a series circuit.

Substituting:

$$E_T = (R_1 \times I_1) + (R_2 \times I_2) + (R_3 \times I_3)$$

$$E_T = (20 \text{ ohms} \times 2 \text{ amps}) + (30 \text{ ohms} \times 2 \text{ amps}) + (50 \text{ ohms} \times 2 \text{ amps})$$

$$E_T = 40 \text{ volts} + 60 \text{ volts} + 100 \text{ volts}$$

$$E_T = 200 \text{ volts}$$

NOTE: When you use Ohm's law, the quantities for the equation MUST be taken from the SAME part of the circuit. In the above example the voltage across R_2 was computed using the current through R_2 and the resistance of R_2.

The value of the voltage dropped by a resistor is determined by the applied voltage and is in proportion to the circuit resistances. The voltage drops that occur in a series circuit are in direct proportion to the resistances. This is the result of having the same current flow through each resistor—the larger the ohmic value of the resistor, the larger the voltage drop across it.

Q17. A series circuit consisting of three resistors has a current of 3 amps. If R_1 = 20 ohms, R_2 = 60 ohms, and R_3 = 80 ohms, what is the (a) total resistance and (b) source voltage of the circuit?

Q18. What is the voltage dropped by each resistor of the circuit described in question 17?

Q19. If the current was increased to 4 amps, what would be the voltage drop across each resistor in the circuit described in question 17?

Q20. What would have to be done to the circuit described in question 17 to increase the current to 4 amps?

Power in a Series Circuit

Each of the resistors in a series circuit consumes power which is dissipated in the form of heat. Since this power must come from the

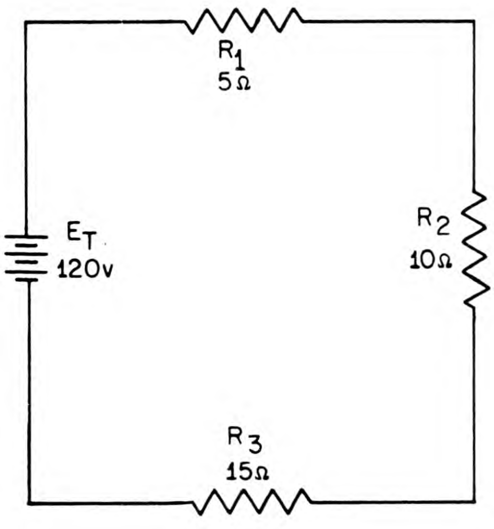


Figure 3-19.—Solving for total power in a series circuit.

source, the total power must be equal to the power consumed by the circuit resistances. In a series circuit the total power is equal to the SUM of the power dissipated by the individual resistors. Total power (P_T) is equal to:

$$P_T = P_1 + P_2 + P_3 + \ldots P_n$$

Example: A series circuit consists of three resistors having values of 5 ohms, 10 ohms, and 15 ohms. Find the total power when 120 volts is applied to the circuit. (See fig. 3-19.)

Given:

R_1 = 5 ohms

R_2 = 10 ohms

R_3 = 15 ohms

E = 120 volts

Solution: The total resistance is found first.

$$R_T = R_1 + R_2 + R_3$$

$$R_T = 5 \text{ ohms} + 10 \text{ ohms} + 15 \text{ ohms}$$

$$R_T = 30 \text{ ohms}$$

By using the total resistance and the applied voltage, the circuit current is calculated.

$$I = \frac{E_T}{R_T}$$

$$I = \frac{120 \text{ volts}}{30 \text{ ohms}}$$

$$I = 4 \text{ amps}$$

By means of the power formulas, the power can be calculated for each resistor:

For R_1:

$$P_1 = I^2 \times R_1$$

$$P_1 = (4 \text{ amps})^2 \times 5 \text{ ohms}$$

$$P_1 = 80 \text{ watts}$$

For R_2:

$$P_2 = I^2 \times R_2$$

$$P = (4 \text{ amps})^2 \times 10 \text{ ohms}$$

$$P_2 = 160 \text{ watts}$$

For R_3:

$$P_3 = I^2 \times R_3$$

$$P = (4 \text{ amps})^2 \times 15 \text{ ohms}$$

$$P_3 = 240 \text{ watts}$$

To obtain total power:

$$P_T = P_1 + P_2 + P_3$$

$$P_T = 80 \text{ watts} + 160 \text{ watts} + 240 \text{ watts}$$

$$P_T = 480 \text{ watts}$$

To check the answer, the total power delivered by the source can be calculated:

$$P_{source} = I_{source} \times E_{source}$$

$$P_{source} = 4 \text{ amps} \times 120 \text{ volts}$$

$$P_{source} = 480 \text{ watts}$$

The total power is equal to the sum of the power used by the individual resistors.

SUMMARY OF CHARACTERISTICS

The important factors governing the operation of a series circuit are listed below. These factors have been set up as a group of

A17. **(a) 160 ohms**

(b) 480 volts

A18. **E_1 = 60 volts**

E_2 = 180 volts

E_3 = 240 volts

A19. **E_1 = 80 volts**

E_2 = 240 volts

E_3 = 320 volts

A20. **The source voltage would have to be increased to 640 volts**

---

rules so that they may be easily studied. These rules must be completely understood before the study of more advanced circuit theory is undertaken.

Rules For Series D.C. Circuits

1. The same current flows through each part of a series circuit.
2. The total resistance of a series circuit is equal to the sum of the individual resistances.
3. The total voltage across a series circuit is equal to the sum of the individual voltage drops.
4. The voltage drop across a resistor in a series circuit is proportional to the ohmic value of the resistor.
5. The total power in a series circuit is equal to the sum of the individual powers used by each circuit component.

SERIES CIRCUIT ANALYSIS

To establish a procedure for solving series circuits, the following sample problems will be solved.

Example: Three resistors of 5 ohms, 10 ohms, and 15 ohms are connected in series with a power source of 90 volts as shown in figure 3-20. Find the total resistance, circuit current, voltage drop of each resistor, power of each resistor, and total power of the circuit.

In solving the circuit the total resistance will be found first. Next, the circuit current will be calculated. Once the current is known, the voltage drops and power dissipations can be calculated.

Given:

R_1 = 5 ohms

R_2 = 10 ohms

R_3 = 15 ohms

E_T = 90 volts

Solution:

$R_T = R_1 + R_2 + R_3$

R_T = 5 ohms + 10 ohms + 15 ohms

R_T = 30 ohms

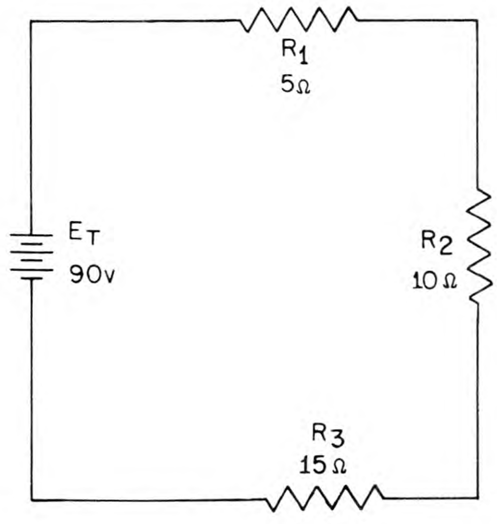


Figure 3-20.—Solving for various values in a series circuit.

$$I = \frac{E_T}{R_T}$$

$$I = \frac{90 \text{ volts}}{30 \text{ ohms}}$$

$I = 3$ amps

$E_1 = IR_1$

$E_1 = 3$ amps x 5 ohms

$E_1 = 15$ volts

$E_2 = IR_2$

$E_2 = 3$ amps x 10 ohms

$E_2 = 30$ volts

$E_3 = IR_3$

$E_3 = 3$ amps x 15 ohms

$E_3 = 45$ volts

$P_1 = I \times E_1$

$P_1 = 3$ amps x 15 volts

$P_1 = 45$ watts

$P_2 = I \times E_2$

$P_2 = 3$ amps x 30 volts

$P_2 = 90$ watts

$P_3 = I \times E_3$

$P_3 = 3$ amps x 45 volts

$P_3 = 135$ watts

$P_T = E_T \times I$

$P_T = 90$ volts x 3 amps

$P_T = 270$ watts

or

$P_T = P_1 + P_2 + P_3$

$P_T = 45$ watts + 90 watts + 135 watts

$P_T = 270$ watts

Example: Four resistors, $R_1 = 10$ ohms, $R_2 = 10$ ohms, $R_3 = 50$ ohms, and $R_4 = 30$ ohms, are connected in series with a power source as shown in figure 3-21. The current through the circuit is 1/2 ampere.

a. What is the battery voltage?

b. What is the voltage across each resistor?

c. What is the power expended in each resistor?

d. What is the total power?

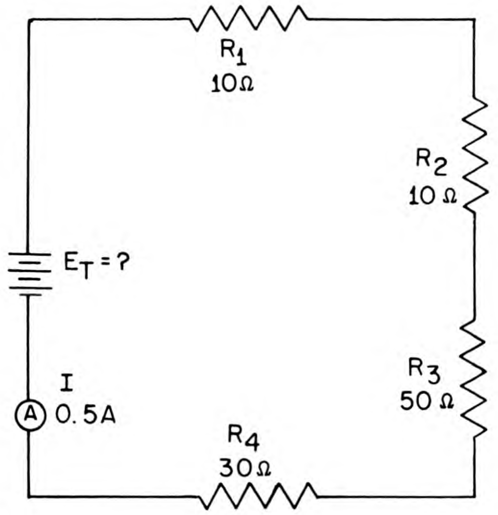


Figure 3-21.—Computing series circuit values.

Given:

R_1 = 10 ohms

R_2 = 10 ohms

R_3 = 50 ohms

R_4 = 30 ohms

I = 0.5 amp

Solution (a):

$E_T = IR_T$

$R_T = R_1 + R_2 + R_3 + R_4$

R_T = 10 ohms + 10 ohms + 50 ohms + 30 ohms

R_T = 100 ohms

E_T = 0.5 amp x 100 ohms

E_T = 50 volts

Solution (b):

$E_1 = IR_1$
E_1 = 0.5 amp x 10 ohms
E_1 = 5 volts

$E_2 = IR_2$
E_2 = 0.5 amp x 10 ohms
E_2 = 5 volts

$E_3 = IR_3$

E_3 = 0.5 amp x 50 ohms

E_3 = 25 volts

$E_4 = IR_4$

E_4 = 0.5 amp x 30 ohms

E_4 = 15 volts

Solution (c):

$P_1 = IE_1$
P_1 = 0.5 amp x 5 volts
P_1 = 2.5 watts

$P_2 = IE_2$
P_2 = 0.5 amp x 5 volts
P_2 = 2.5 watts

$P_3 = IE_3$
P_3 = 0.5 amp x 25 volts
P_3 = 12.5 watts

$P_4 = IE_4$
P_4 = 0.5 amp x 15 volts
P_4 = 7.5 watts

Solution (d):

$P_T = P_1 + P_2 + P_3 + P_4$

P_T = 2.5 watts + 2.5 watts + 12.5 watts + 7.5 watts

P_T = 25 watts

or

$P_T = IE_T$

P_T = 0.5 amps x 50 volts

P_T = 25 watts

or

$$P_T = \frac{E_T{}^2}{R_T}$$

$$P_T = \frac{(50 \text{ volts})^2}{100 \text{ ohms}}$$

$$P_T = \frac{2500 \text{ volts}}{100 \text{ ohms}}$$

P_T = 25 watts

An important fact to keep in mind when applying Ohm's law to a series circuit is to consider whether the values used are component values or total values. When the information available enables the use of Ohm's law to find total resistance, total voltage, and total current, total values must be inserted into the formula. To find total resistance:

$$R_T = \frac{E_T}{I_T}$$

To find total voltage:

$$E_T = I_T \times R_T$$

To find total current:

$$I_T = \frac{E_T}{R_T}$$

NOTE: I_T is equal to I in a series circuit. However, the distinction between I_T and I in the formula should be noted. The reason for this is that future circuits may have several currents, and it will be necessary to differentiate between I_T and other currents.

To compute any quantity (E, I, R, or P) associated with a single given resistor, the values used in the formula must be obtained from that particular resistor. For example, to find the value of an unknown resistance, the voltage across and the current through that particular resistor must be used.

To find the value of a resistor:

$$R = \frac{E_R}{I_R}$$

To find the voltage drop across a resistor:

$$E_R = I_R \times R$$

To find current through a resistor:

$$I_R = \frac{E_R}{R}$$

Q21. A series circuit consists of two resistors in series. R_1 = 25 ohms and R_2 = 30 ohms. The circuit current is 6 amps. What is the (a) source voltage, (b) voltage dropped by each resistor, (c) total power, and (d) power used by each resistor?

KIRCHHOFF'S VOLTAGE LAW

In 1847, G. R. Kirchhoff extended the use of Ohm's law by developing a simple concept concerning the voltages contained in a series circuit loop. Kirchhoff's law states:

> "The algebraic sum of the voltage drops in any closed path in a circuit and the electromotive forces in that path is equal to zero."

To state Kirchhoff's law another way, the voltage drops and voltage sources in a circuit are equal at any given moment in time. If the voltage sources are assumed to have one sign (positive or negative) at that instant and the voltage drops are assumed to have the opposite sign, the result of adding the voltage sources and voltage drops will be zero.

NOTE: The terms electromotive force and emf are used when explaining Kirchhoff's law because Kirchhoff's law is used in alternating current circuits (covered in Module 2). In applying Kirchhoff's law to direct current circuits, the terms electromotive force and emf apply to voltage sources such as batteries or power supplies.

Through the use of Kirchhoff's law, circuit problems can be solved which would be difficult, and often impossible, with knowledge of Ohm's law alone. When Kirchhoff's law is properly applied, an equation can be set up for a closed loop and the unknown circuit values can be calculated.

POLARITY OF VOLTAGE

To apply Kirchhoff's voltage law, the meaning of voltage polarity must be understood.

A21. (a) 330 volts

(b) E_1 = 150 volts
E_2 = 180 volts

(c) 1.98 kilowatts

(d) P_1 = 900 watts
P_2 = 1.08 kilowatts

In the circuit shown in figure 3-22, the current is shown flowing in a counterclockwise direction. Notice that the end of resistor R_1, into which the current flows, is marked NEGATIVE (-). The end of R_1 at which the current leaves is marked POSITIVE (+). These polarity markings are used to show that the end of R_1 into which the current flows is at a higher negative potential than the end of the resistor at which the current leaves. Point A is more negative than point B.

Point C, which is at the same potential as point B, is labeled negative. This is to indicate that point C is more negative than point D. To say a point is positive (or negative) without stating what the polarity is based upon has no meaning. In working with Kirchhoff's law, positive and negative polarities are assigned in the direction of current flow.

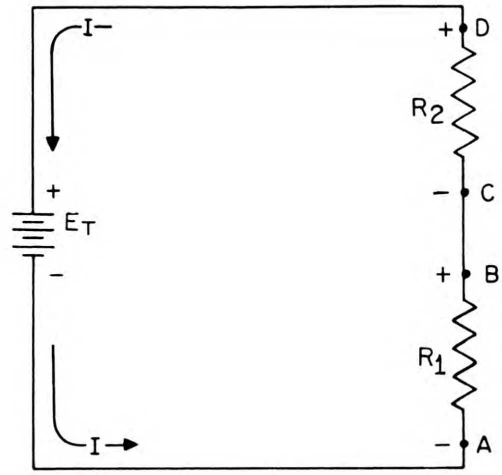


Figure 3-22.—Voltage polarities.

APPLICATION OF KIRCHHOFF'S VOLTAGE LAW

Kirchhoff's voltage law can be written as an equation, as shown below:

$$E_a + E_b + E_c + \ldots E_n = 0$$

where E_a, E_b, etc., are the voltage drops or emf's around any closed circuit loop. To set up the equation for an actual circuit, the following procedure is used.

1. Assume a direction of current through the circuit. (The correct direction is desirable but not necessary.)
2. Using the assumed direction of current, assign polarities to all resistors through which the current flows.
3. Place the correct polarities on any sources included in the circuit.
4. Starting at any point in the circuit, trace around the circuit, writing down the amount and polarity of the voltage across each component in succession. The polarity used is the sign AFTER the assumed current has passed through the component. Stop when the point at which the trace was started is reached.
5. Place these voltages, with their polarities, into the equation and solve for the desired quantity.

Example: Three resistors are connected across a 50 volt source. What is the voltage across the third resistor if the voltage drops across the first two resistors are 25 volts and 15 volts?

Solution: First, a diagram, such as the one shown in figure 3-23, is drawn. Next, a direction of current is assumed (as shown). Using this current, the polarity markings are placed at each end of each resistor and also on the terminals of the source. Starting at point A, trace around the circuit in the direction of current flow, recording the voltage and polarity of each component. Starting at point A and using the components from the circuit:

$$(+E_x) + (+E_2) + (+E_1) + (-E_A) = 0$$

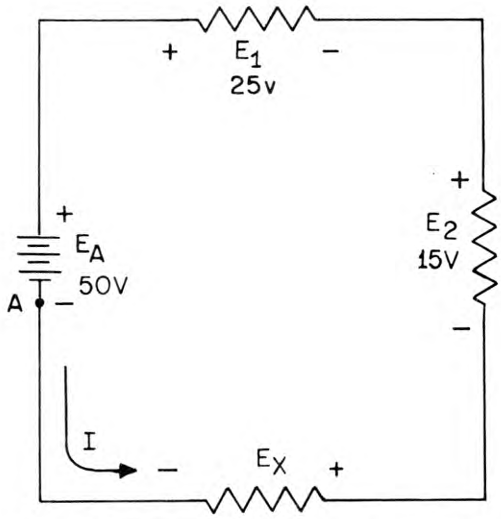


Figure 3-23.—Determining unknown voltage in a series circuit.

Substituting values from the circuit:

$$E_X + 15 \text{ volts} + 25 \text{ volts} - 50 \text{ volts} = 0$$

$$E_X - 10 \text{ volts} = 0$$

$$E_X = 10 \text{ volts}$$

The unknown voltage (E_X) is found to be 10 volts.

Using the same idea as above, you can solve a problem in which the current is the unknown quantity.

Example: A circuit having a source voltage of 60 volts contains three resistors of 5 ohms, 10 ohms, and 15 ohms. Find the circuit current.

Solution: Draw and label the circuit (fig. 3-24). Establish a direction of current flow and assign polarities. Next, starting at any point—point A will be used in this example—write out the loop equation.

Basic equation:

$$E_2 + E_1 + E_A + E_3 = 0$$

Since E = IR, by substitution:

$$(I \times R_2) + (I \times R_1) + E_A + (I \times R_3) = 0$$

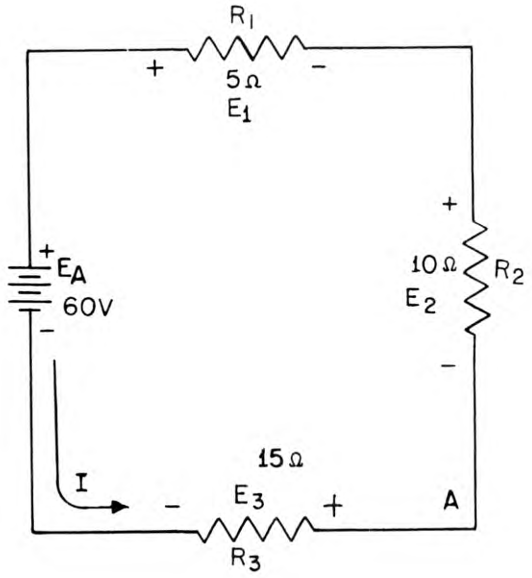


Figure 3-24.—Correct direction of assumed current.

Substituting values:

$$(I \times 10 \text{ ohms}) + (I \times 5 \text{ ohms}) + (-60 \text{ volts}) + (I \times 15 \text{ ohms}) = 0$$

Combining like terms:

$$(I \times 30 \text{ ohms}) + (-60 \text{ volts}) = 0$$

$$I \times 30 \text{ ohms} = 60 \text{ volts}$$

$$I = \frac{60 \text{ volts}}{30 \text{ ohms}}$$

$$I = 2 \text{ amps}$$

Since the current obtained in the above calculations is a positive 2 amps, the assumed direction of current was correct. To show what happens if the incorrect direction of current is assumed, the problem will be solved as before, but with the opposite direction of current. The circuit is redrawn showing the new direction of current and new polarities in figure 3-25. Starting at point A the loop equation is:

$$E_3 + E_A + E_1 + E_2 = 0$$

$$(I \times R_3) + E_A + (I \times R_1) + (I \times R_2) = 0$$

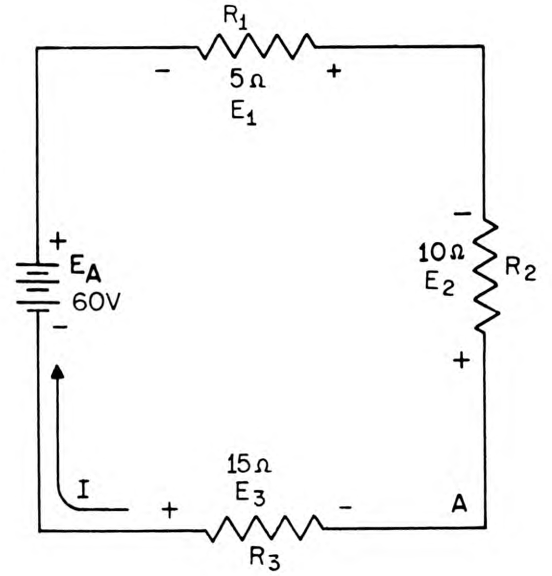


Figure 3-25.—Incorrect direction of assumed current.

Substituting values:

$$(I \times 15 \text{ ohms}) + 60 \text{ volts} + (I \times 5 \text{ ohms}) + (I \times 10 \text{ ohms}) = 0$$

Combining like terms:

$$(I \times 30 \text{ ohms}) + 60 \text{ volts} = 0$$

$$I \times 30 \text{ ohms} = -60 \text{ volts}$$

$$I = \frac{-60 \text{ volts}}{30 \text{ ohms}}$$

$$I = -2 \text{ amps}$$

Notice that the AMOUNT of current is the same as before. The polarity, however, is NEGATIVE. The negative polarity simply indicates the wrong direction of current was assumed. Should it be necessary to use this current in further calculations on the circuit using Kirchhoff's law, the negative polarity should be retained in the calculations.

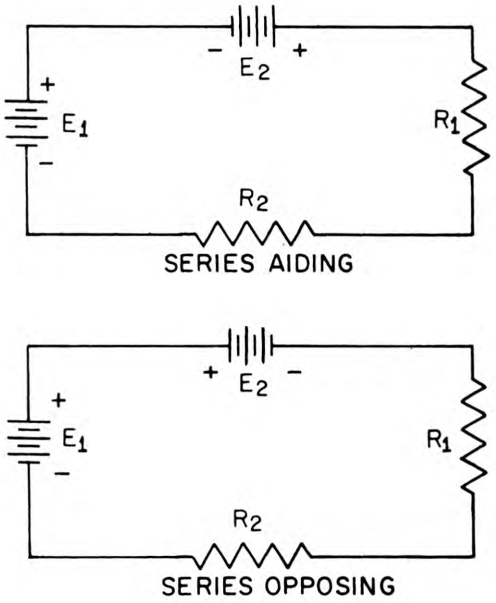
Series Aiding and Opposing Sources

In many practical applications a circuit may contain more than one source of emf. Sources of emf that cause current to flow in the same direction are considered to be SERIES AIDING and the voltages are added. Sources of emf that would tend to force current in opposite directions are said to be SERIES OPPOSING, and the effective source voltage is the difference between the opposing voltages. When two opposing sources are inserted into a circuit, current flow would be in a direction determined by the larger source. Examples of series aiding and opposing sources are shown in figure 3-26.

A simple solution may be obtained for a multiple-source circuit through the use of Kirchhoff's voltage law. In applying this method, the same procedure is used for the multiple-source circuit as was used above for the single-source circuit. This is demonstrated by the following.

Example: Using Kirchhoff's voltage equation, find the amount of current in the circuit shown in fig 3-27.

Solution: As before, a direction of current flow is assumed and polarity signs are placed on



(A) Series Aiding.
(B) Series Opposing.
Figure 3-26.—Aiding and opposing sources.

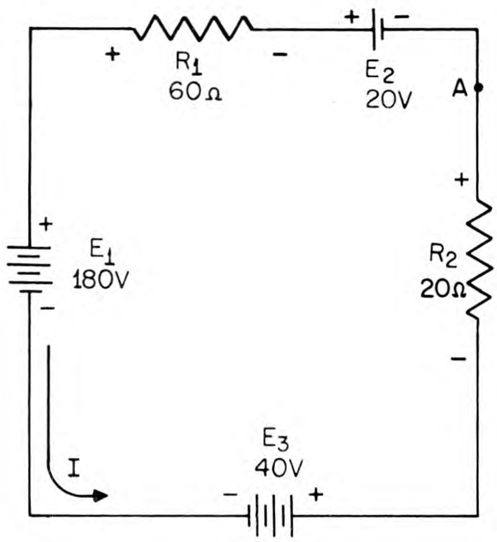


Figure 3-27.—Solving for circuit current using Kirchhoff's voltage current.

the drawing. The loop equation will be started at point A.

$$E_2 + E_{R1} + E_1 + E_3 + E_{R2} = 0$$

$$20 \text{ volts} + (I \times 60 \text{ ohms}) + (-180 \text{ volts}) + 40 \text{ volts} + (I \times 20 \text{ ohms}) = 0$$

$$20 \text{ volts} - 180 \text{ volts} + 40 \text{ volts} + (I \times 60 \text{ ohms}) + (I \times 20 \text{ ohms}) = 0$$

$$-120 \text{ volts} + (I \times 80 \text{ ohms}) = 0$$

$$I \times 80 \text{ ohms} = 120 \text{ volts}$$

$$I = \frac{120 \text{ volts}}{80 \text{ ohms}}$$

$$I = 1.5 \text{ amps}$$

Q22. When using Kirchhoff's voltage law, how are voltage polarities assigned to the voltage drops across resistors?

Q23. Refer to figure 3-27, if R_1 was changed to a 40 ohm resistor, what would be the value of circuit current (I_T)?

Q24. Refer to figure 3-27. What is the effective source voltage of the circuit using the 40 ohm resistor?

CIRCUIT TERMS AND CHARACTERISTICS

Before you learn about the types of circuits other than the series circuit, you should become familiar with some of the terms and characteristics used in electrical circuits. These terms and characteristics will be used throughout your study of electricity and electronics.

REFERENCE POINT

A reference point is an arbitrarily chosen point to which all other points in the circuit are compared. In series circuits, any point can be chosen as a reference and the electrical potential at all other points can be determined in reference to that point. In figure 3-28 point A shall be considered the reference point. Each series resistor in the illustrated circuit is of equal value. The applied voltage is equally distributed across each resistor. The potential at point B is 25 volts more positive than at point A. Points C and D are 50 volts and 75 volts, more positive than point A respectively.

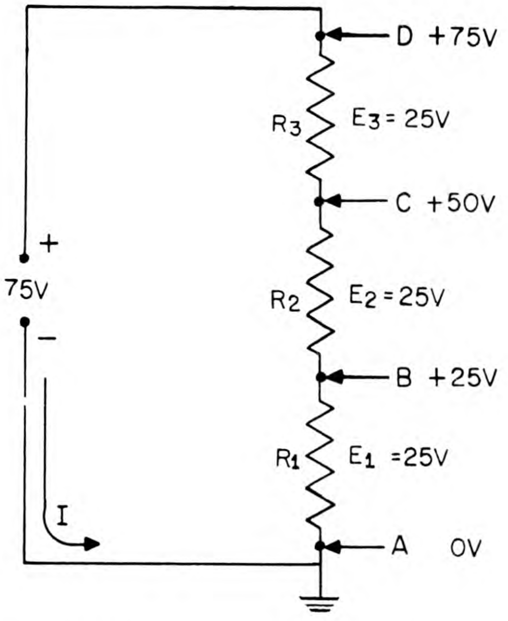


Figure 3-28.—Reference points in a series circuit.

A22. **The point at which current enters the resistor is assigned a negative polarity and the point at which current leaves the resistor is assigned a positive polarity.**

A23. 2 amperes

A24. 120 volts

When point B is used as the reference, as in figure 3-29, point D would be positive 50 volts in respect to the new reference point. The former reference point, A, is 25 volts negative in respect to point B.

As in the previous circuit illustration, the reference point of a circuit is always considered to be at zero potential. Since the earth (ground) is said to be at a zero potential, the term GROUND is used to denote a common electrical point of zero potential. In figure 3-30, point A is the zero reference, or ground, and the symbol for ground is shown connected to point A. Point C is 75 volts positive in respect to ground.

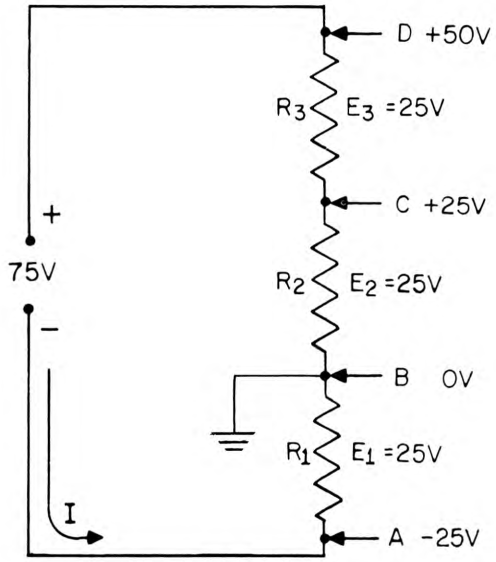


Figure 3-29.—Determining potentials with respect to a reference point.

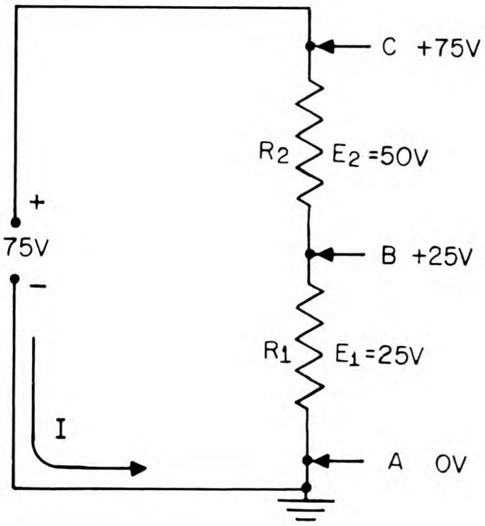


Figure 3-30.—Use of ground symbols.

In most electrical equipment, the metal chassis is the common ground for the many electrical circuits. When each electrical circuit is completed, common points of a circuit at zero potential are connected directly to the metal chassis, thereby eliminating a large amount of connecting wire. The electrons pass through the

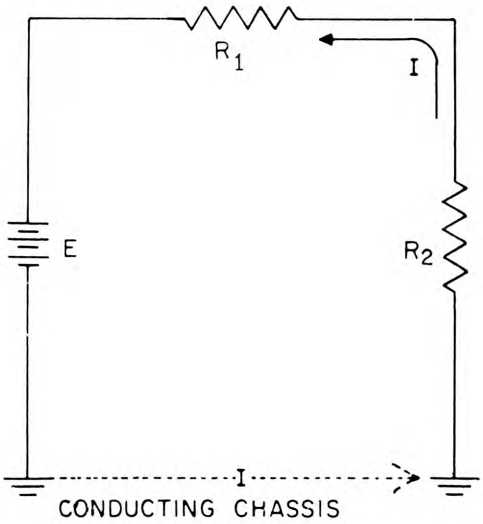


Figure 3-31.—Ground used as a conductor.

metal chassis (a conductor) to reach other points of the circuit. An example of a chassis grounded circuit is illustrated in figure 3-31.

Most voltage measurements used to check proper circuit operation in electrical equipment are taken in respect to ground. One meter lead is attached to a grounded point and the other meter lead is moved to various test points. Circuit measurement is explained in more detail in NEETS Module 3.

OPEN CIRCUIT

A circuit is said to be OPEN when a break exists in a complete conducting pathway. Although an open occurs when a switch is used to deenergize a circuit, an open may also develop accidentally. To restore a circuit to proper operation, the open must be located, its cause determined, and repairs made.

Sometimes an open can be located visually by a close inspection of the circuit components. Defective components, such as burned out resistors, can usually be discovered by this method. Others, such as a break in wire covered by insulation or the melted element of an enclosed fuse, are not visible to the eye. Under such conditions, the understanding of the effect an open has on circuit conditions enables a technician to make use of test equipment to locate the open component.

In figure 3-32, the series circuit consists of two resistors and a fuse. Notice the effects on circuit conditions when the fuse opens.

Current ceases to flow; therefore, there is no longer a voltage drop across the resistors. Each end of the open conducting path becomes an extension of the battery terminals and the voltage felt across the open is equal to the applied voltage (E_A).

An open circuit has INFINITE resistance. INFINITY represents a quantity so large it cannot be measured. The symbol for infinity is ∞. In an open circuit, $R_T = \infty$.

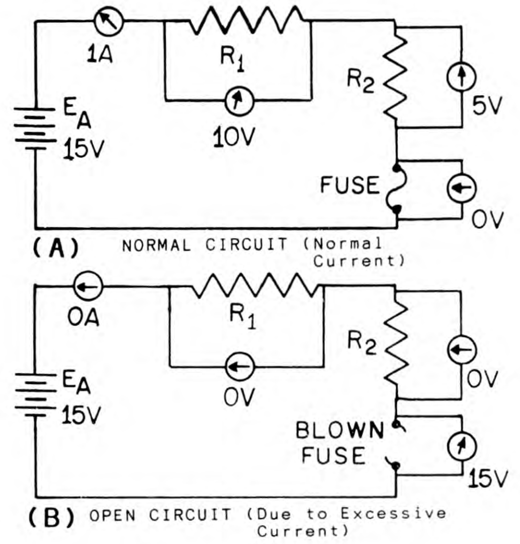

1A
R1
R2
5V
EA
15V
10V
FUSE
0V
(A) NORMAL CIRCUIT (Normal Current)
0A
R1
R2
0V
EA
15V
0V
BLOWN FUSE
15V
(B) OPEN CIRCUIT (Due to Excessive Current)

Figure 3-32.—Normal and open circuit conditions. (A) Normal Current (B) Excessive Current.

SHORT CIRCUIT

A short circuit is an accidental path of low resistance which passes an abnormally high amount of current. A short circuit exists whenever the resistance of a circuit or the resistance of a part of a circuit drops in value to almost zero ohms. A short often occurs as a result of improper wiring or broken insulation.

In figure 3-33, a short is caused by improper wiring. Note the effect on current flow. Since the resistor has in effect been replaced with a piece of wire, practically all the current flows through the short and very little current flows through the resistor. Electrons flow through the short (a path of almost zero resistance) and the remainder of the circuit by passing through the 10-ohm resistor and the battery. The amount of current flow increases greatly because its resistive path has decreased from 10,010 ohms to 10 ohms. Due to the excessive current flow, the 10-ohm resistor becomes heated. As it attempts to dissipate this heat, the resistor will probably be destroyed. Figure 3-34 shows a pictorial wiring diagram, rather than a schematic diagram, to indicate how broken insulation might cause a short circuit.

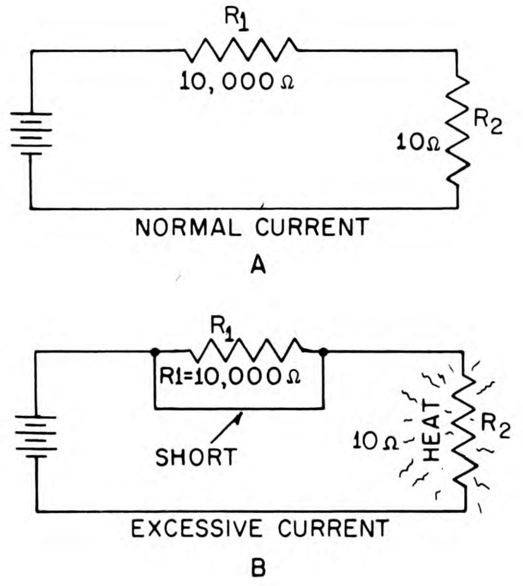


Figure 3-33.—Normal and short circuit conditions.

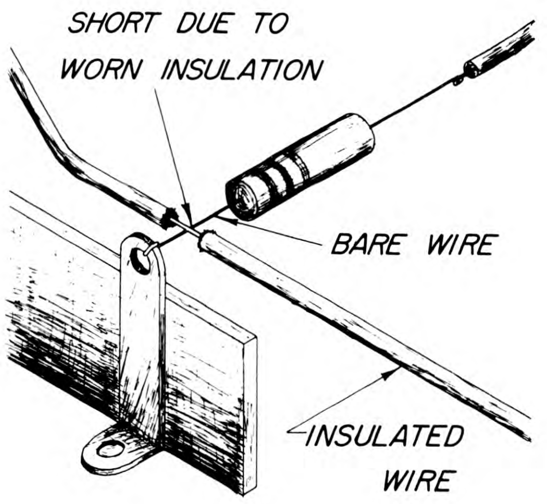


Figure 3-34.—Short due to broken insulation.

SOURCE RESISTANCE

A meter connected across the terminals of a good 1.5-volt battery reads about 1.5 volts. When the same battery is inserted into a complete circuit, the meter reading decreases to something less than 1.5-volts. This difference in terminal voltage is caused by the INTERNAL RESISTANCE of the battery (the opposition to current offered by the electrolyte in the battery). All sources of electromotive force have some form of internal resistance which causes a drop in terminal voltage as current flows through the source.

This principle is illustrated in figure 3-35, where the internal resistance of a battery is shown as R_i. In the schematic, the internal resistance is indicated by an additional resistor in series with the battery. The battery, with its internal resistance, is enclosed within the dotted lines of the schematic diagram. With the switch open, the voltage across the battery terminals reads 15 volts. When the switch is closed, current flow causes voltage drops around the circuit. The circuit current of 2 amperes causes a voltage drop of 2 volts across R_i. The 1 ohm internal battery resistance thereby drops the battery terminal voltage to 13 volts. Internal resistance cannot be measured directly with a meter. An attempt to do this would damage the meter.

The effect of the source resistance on the power output of a d.c. source may be shown by an analysis of the circuit in figure 3-36. When the variable load resistor (R_L) is set at the zero ohm position (equivalent to a short circuit) current (I) is calculated using the following formula:

$$I = \frac{E_s}{R_i} = \frac{100\text{ volts}}{5\text{ ohms}} = 20\text{ amperes}$$

This is the maximum current that may be drawn from the source. The terminal voltage across the short circuit is zero volts and all the voltage is across the resistance within the source.

If the load resistance (R_L) were increased (the internal resistance remaining the same), the current drawn from the source would decrease. Consequently, the voltage drop across the internal resistance would decrease. At the same time, the terminal voltage applied across the

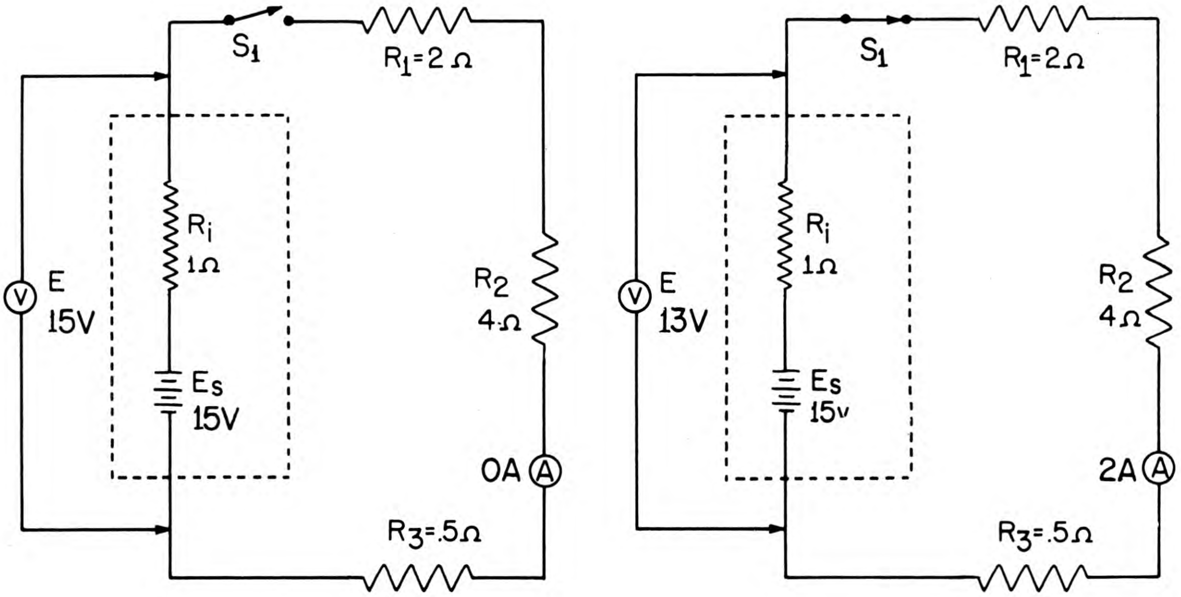


Figure 3-35.—Effect of internal resistance.

load would increase and approach a maximum as the current approaches zero amps.

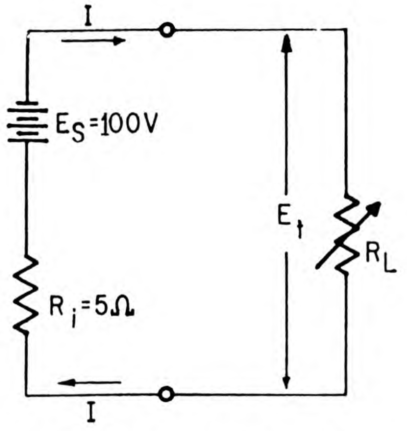
POWER TRANSFER AND EFFICIENCY

Maximum power is transferred from the source to the load when the resistance of the load is equal to the internal resistance of the source. This theory is illustrated in the table and the graph of figure 3-36. When the load resistance is 5 ohms, matching the source resistance, the maximum power of 500 watts is developed in the load.

The efficiency of power transfer (ratio of output power to input power) from the source to the load increases as the load resistance is increased. The efficiency approaches 100 percent as the load resistance approaches a relatively large value compared with that of the source, since less power is lost in the source. The efficiency of power transfer is only 50 percent at the maximum power transfer point (when the load resistance equals the internal resistance of the source). The efficiency of power transfer approaches zero efficiency when the load resistance is relatively small compared with the internal resistance of the source. This is also shown on the chart of figure 3-36.

The problem of a desire for both high efficiency and maximum power transfer is resolved by a compromise between maximum power transfer and high efficiency. Where the amounts of power involved are large and the efficiency is important, the load resistance is made large relative to the source resistance so that the losses are kept small. In this case, the efficiency is high. Where the problem of matching a source to a load is important, as in communications circuits, a strong signal may be more important than a high percentage of efficiency. In such cases, the efficiency of power transfer should be only about 50 percent; however, the power transfer would be the maximum which the source is capable of supplying.

You should now understand the basic concepts of series circuits. The principles which have been presented are of lasting importance. Once equipped with a firm understanding of series circuits, you hold the key to an understanding of the parallel circuits to be presented next.

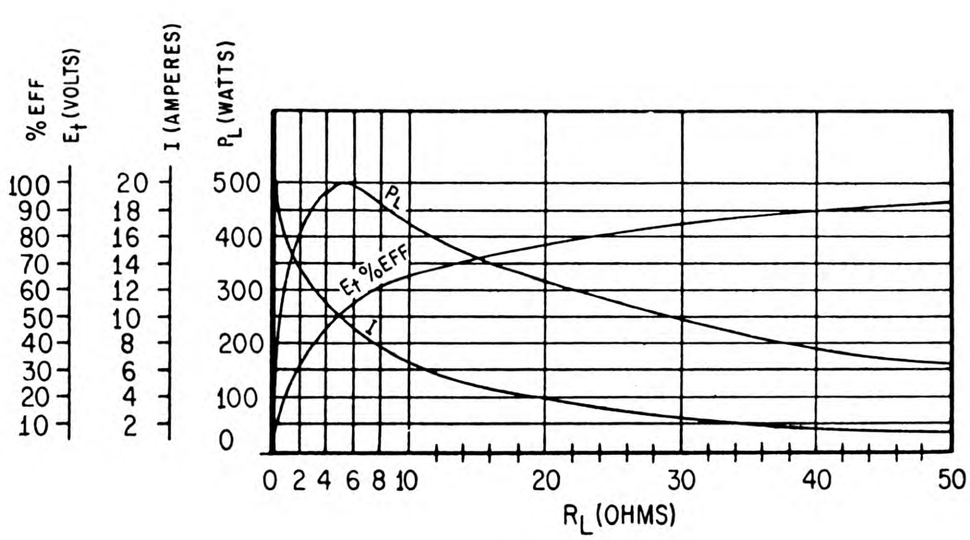


E_S= OPEN-CIRCUIT VOLTAGE OF SOURCE
R_i= INTERNAL RESISTANCE OF SOURCE
E_t= TERMINAL VOLTAGE
R_L= RESISTANCE OF LOAD
P_L= POWER USED IN LOAD
I = CURRENT FROM SOURCE
% EFF. = PERCENTAGE OF EFFICIENCY

(A)
CIRCUIT AND SYMBOL DESIGNATIONS

R_L	E_t	I	P_L	% EFF.
0	0	20	0	0
1	16.7	16.7	278.9	16.7
2	28.6	14.3	409	28.6
3	37.5	12.5	468.8	37.5
4	44.4	11.1	492.8	44.4
5	50	10	500	50
6	54.5	9.1	496.0	54.5
7	58.3	8.3	483.9	58.3
8	61.6	7.7	474.3	61.6
9	64.3	7.1	456.5	64.3
10	66.7	6.7	446.9	66.7
20	80	4	320	80
30	85.7	2.9	248.5	85.7
40	88.9	2.2	195.6	88.9
50	90.9	1.9	172.7	90.9

(B)
CHART



(C)
GRAPH

Figure 3-36.—Effect of source resistance on power output.

Q25. A circuit has a source voltage of 100 volts and two 50 ohm resistors connected in series. If the reference point for this circuit is placed between the two resistors, what would be the voltage at the reference point?

Q26. If the reference point in question 25 was connected to ground, what would be the voltage level of the reference point?

Q27. What is an open circuit?

Q28. What is a short circuit?

Q29. Why will a meter indicate more voltage at the battery terminal when the battery is out of a circuit than when the battery is in a circuit?

Q30. What condition gives maximum power transfer from the source to the load?

Q31. What is the efficiency of power transfer in question 30?

Q32. A circuit has a source voltage of 25 volts. The source resistance is 1 ohm and the load resistance is 49 ohms. What is the efficiency of power transfer?

PARALLEL D.C. CIRCUITS

The discussion of electrical circuits presented up to this point has been concerned with series circuits in which there is only one path for current. There is another basic type of circuit known as the PARALLEL CIRCUIT with which you must become familiar. Where the series circuit has only one path for current, the parallel circuit has more than one path for current.

Ohm's law and Kirchhoff's law apply to all electrical circuits, but the characteristics of a parallel d.c. circuit are different than those of a series d.c. circuit.

PARALLEL CIRCUIT CHARACTERISTICS

A PARALLEL CIRCUIT is defined as one having more than one current path connected to a common voltage source. Parallel circuits, therefore, must contain two or more resistances which are not connected in series. An example of a basic parallel circuit is shown in figure 3-37.

Start at the voltage source (E_s) and trace counterclockwise around the circuit. Two complete and separate paths can be identified in which current can flow. One path is traced from the source, through resistance R_1, and back to the source. The other path is from the source, through resistance R_2, and back to the source.

Voltage in a Parallel Circuit

You have seen that the source voltage in a series circuit divides proportionately across each resistor in the circuit. IN A PARALLEL CIRCUIT, THE SAME VOLTAGE IS PRESENT IN EACH BRANCH. (A branch is a section of a circuit that has a complete path for current.) In figure 3-37 this voltage is equal to the applied

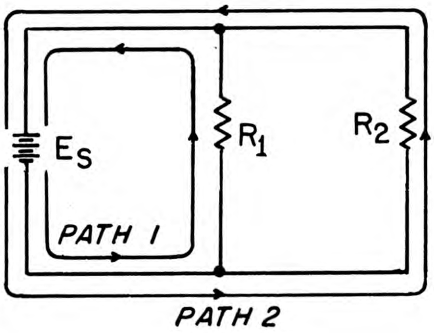


Figure 3-37.—Example of a basic parallel circuit.

A25. 50 volts

A26. Zero volts

A27. A circuit where there is no longer a complete path for current flow

A28. A accidental path of low resistance which passes an abnormally high amount of current

A29. The internal (source) resistance of the battery will drop some of the voltage

A30. When the load resistance equals the source resistance

A31. 50 percent

A32. 98 percent $\left(\frac{12.25 \text{ watts}}{12.5 \text{ watts}} \times 100\right)$

---

voltage (E_s). This can be expressed in equation form as:

$$E_s = E_{R1} = E_{R2}$$

Voltage measurements taken across the resistors of a parallel circuit, as illustrated by figure 3-38, verify this equation. Each meter indicates the same amount of voltage. Notice that the voltage across each resistor is the same as the applied voltage.

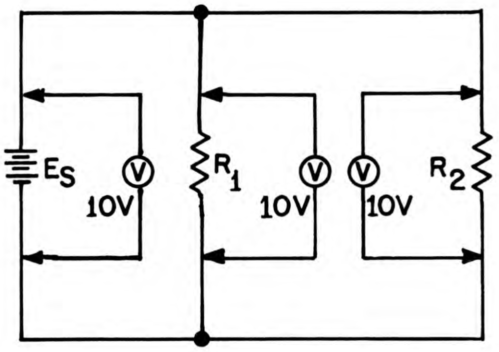


Figure 3-38.—Voltage comparison in a parallel circuit.

Example: Assume that the current through a resistor of a parallel circuit is known to be 4.5 milliamperes (4.5mA) and the value of the resistor is 30,000 ohms (30kΩ). Determine the source voltage. The circuit is shown in figure 3-39.

Given:

R_2 = 30,000 ohms (30kΩ)

I_{R2} = 4.5 milliamps (4.5mA or .0045 amps)

Solution:

$$E = IR$$

$$E_{R2} = .0045 \text{ amp} \times 30,000 \text{ ohms}$$

$$E_{R2} = 135 \text{ volts}$$

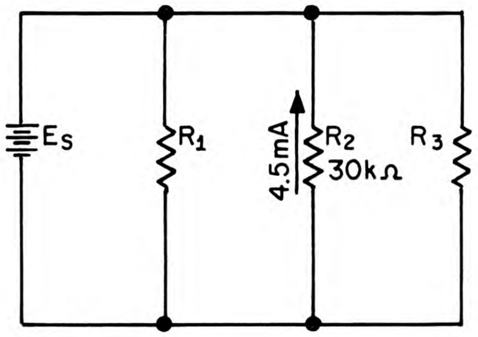


Figure 3-39.—Example problem parallel circuit.

Since the source voltage is equal to the voltage of a branch:

$$E_s = E_{R2}$$

$$E_s = 135 \text{ volts}$$

To simplify the math operation, the values can be expressed in powers of ten as follows:

$$30{,}000 \text{ ohms} = 30 \times 10^3 \text{ ohms}$$

$$4.5\text{mA} = 4.5 \times 10^{-3} \text{ amps}$$

$$E_{R2} = (4.5 \times 10^{-3}) \text{ amps} \times (30 \times 10^3) \text{ ohms}$$

$$E_{R2} = (4.5 \times 30 \times 10^{-3} \times 10^3) \text{ volts}$$

$$(10^{-3} \times 10^3 = 10^{-3+3} = 10^0 = 1)$$

$$E_{R2} = (4.5 \times 30 \times 1) \text{ volts}$$

$$E_{R2} = 135 \text{ volts}$$

$$E_s = E_{R2}$$

$$E_s = 135 \text{ volts}$$

If you are not familiar with the use of the powers of 10 or would like to brush up on it, *Mathematics, Vol. 1,* NAVEDTRA 10069-C, will be of great help to you.

Q33. What would the source voltage (E_s) in figure 3-39 be if the current through R_2 was 2 milliamps?

Current in a Parallel Circuit

Ohm's law states that the current in a circuit is inversely proportional to the circuit resistance. This fact is true in both series and parallel circuits.

There is a single path for current in a series circuit. The amount of current is determined by the total resistance of the circuit and the applied voltage. In a parallel circuit the source current divides among the available paths.

The behavior of current in parallel circuits will be shown by a series of illustrations using example circuits with different values of resistance for a given value of applied voltage.

Part (A) of figure 3-40 shows a basic series circuit. Here, the total current must pass through the single resistor. The amount of current can be determined.

Given:

$$E_s = 50 \text{ volts}$$

$$R_1 = 10 \text{ ohms}$$

Solution:

$$I = \frac{E}{R}$$

$$I_T = \frac{E_s}{R_1}$$

$$I_T = \frac{50 \text{ volts}}{10 \text{ ohms}}$$

$$I_T = 5 \text{ amps}$$

Part (B) of figure 3-40 shows the same resistor (R_1) with a second resistor (R_2) of

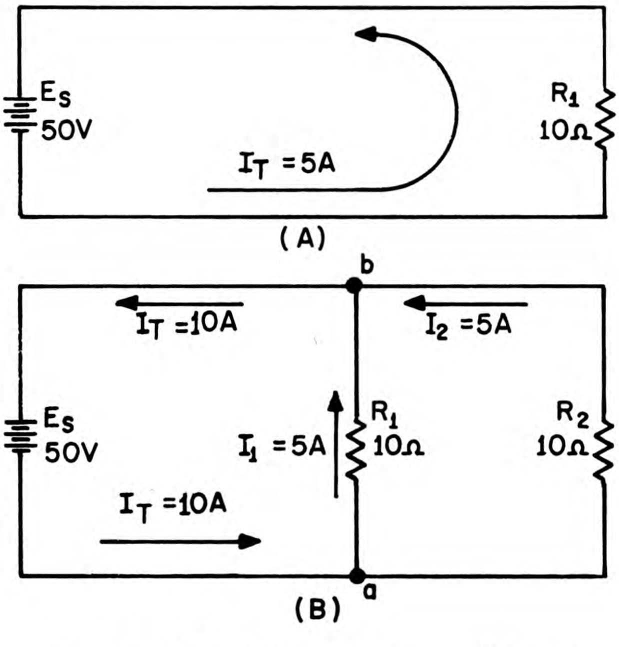


Figure 3-40.—Analysis of current in parallel circuit.

A33. 60 volts

---

equal value connected in parallel across the voltage source. When Ohm's law is applied, the current flow through each resistor is found to be the same as the current through the single resistor in part (A).

Given: $E_s = 50$ volts

$R_1 = 10$ ohms

$R_2 = 10$ ohms

Solution: $I = \frac{E}{R}$

$E_s = E_{R1} = E_{R2}$

$$I_{R1} = \frac{E_{R1}}{R_1}$$

$$I_{R1} = \frac{50 \text{ volts}}{10 \text{ ohms}}$$

$I_{R1} = 5$ amps

$$I_{R2} = \frac{E_{R2}}{R_2}$$

$$I_{R2} = \frac{50 \text{ volts}}{10 \text{ ohms}}$$

$I_{R2} = 5$ amps

It is apparent that if there is 5 amperes of current through each of the two resistors, there must be a TOTAL CURRENT of 10 amperes drawn from the source.

The total current of 10 amperes, as illustrated in figure 3-40(B), leaves the negative terminal of the battery and flows to point a. Since point a is a connecting point for the two resistors, it is called a JUNCTION. At junction a, the total current divides into two currents of 5 amperes each. These two currents flow through their respective resistors and rejoin at junction b. The total current then flows from junction b back to the positive terminal of the source. The source supplies a total current of 10 amperes and each of the two equal resistors carries one-half the total current.

Each individual current path in the circuit of figure 3-40(B) is referred to as a BRANCH. Each branch carries a current that is a portion of the total current. Two or more branches form a NETWORK.

From the previous explanation, the characteristics of current in a parallel circuit can be expressed in terms of the following general equation:

$$I_T = I_1 + I_2 + \ldots I_n$$

Compare part (A) of figure 3-41 with part (B) of the circuit in figure 3-40. Notice that doubling the value of the second branch resistor (R_2) has no effect on the current in the first branch (I_{R1}), but does reduce the second branch current (I_{R2}) to one-half its original value. The total circuit current drops to a value

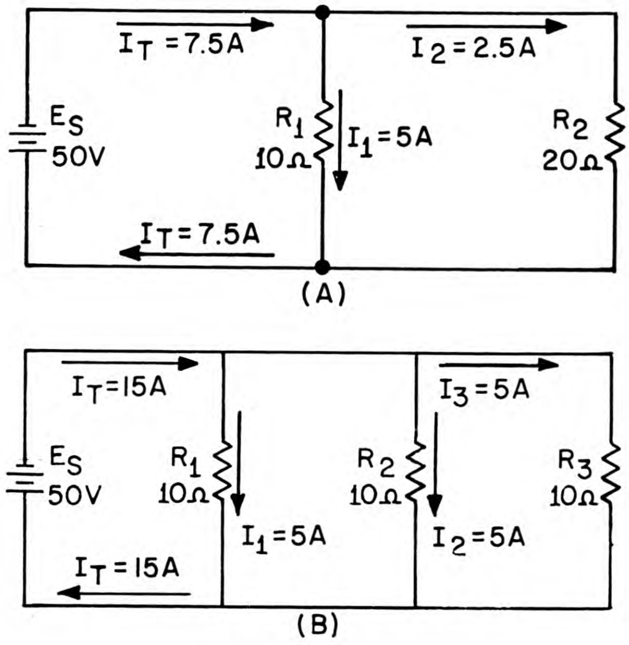


Figure 3-41.—Current behavior in parallel circuits.

equal to the sum of the branch currents. These facts are verified by the following equations.

Given: $E_s = 50$ volts

$R_1 = 10$ ohms

$R_2 = 20$ ohms

Solution: $I = \frac{E}{R}$

$E_s = E_{R\,1} = E_{R\,2}$

$I_{R\,1} = \frac{E_{R\,1}}{R_1}$

$I_{R\,1} = \frac{50 \text{ volts}}{10 \text{ ohms}}$

$I_{R\,1} = 5$ amps

$I_{R\,2} = \frac{E_{R\,2}}{R_2}$

$I_{R\,2} = \frac{50 \text{ volts}}{20 \text{ ohms}}$

$I_{R\,2} = 2.5$ amps

$I_T = I_{R\,1} + I_{R\,2}$

$I_T = 5 \text{ amps} + 2.5 \text{ amps}$

$I_T = 7.5$ amps

The amount of current flow in the branch circuits and the total current in the circuit shown in figure 3-41(B) are determined by the following computations.

Given: $E_s = 50$ volts

$R_1 = 10$ ohms

$R_2 = 10$ ohms

$R_3 = 10$ ohms

Solution: $I = \frac{E}{R}$

$E_s = E_{R\,1} = E_{R\,2} = E_{R\,3}$

$I_{R\,1} = \frac{E_{R\,1}}{R_1}$

$I_{R\,1} = \frac{50 \text{ volts}}{10 \text{ ohms}}$

$I_{R\,1} = 5$ amps

$I_{R\,2} = \frac{E_{R\,2}}{R_2}$

$I_{R\,2} = \frac{50 \text{ volts}}{10 \text{ ohms}}$

$I_{R\,2} = 5$ amps

$I_{R\,3} = \frac{E_{R\,3}}{R_3}$

$I_{R\,3} = \frac{50 \text{ volts}}{10 \text{ ohms}}$

$I_{R\,3} = 5$ amps

$I_T = I_{R\,1} + I_{R\,2} + I_{R\,3}$

$I_T = 5 \text{ amps} + 5 \text{ amps} + 5 \text{ amps}$

$I_T = 15$ amps

Notice that the sum of the ohmic values of the resistors in both circuits shown in figure 3-41 is equal (30 ohms), and that the applied voltage is the same value (50 volts). However, the total current in 3-41(B) (15 amps) is twice the amount in 3-41(A) (7.5 amps). It is apparent, therefore, that the manner in which resistors are connected in a circuit, as well as their actual ohmic values, affect the total current.

The division of current in a parallel network follows a definite pattern. This pattern is described by KIRCHHOFF'S CURRENT LAW which states:

> "The algebraic sum of the currents entering and leaving any junction of conductors is equal to zero."

This law can be stated mathematically as:

$$I_a + I_b + \ldots I_n = 0$$

where: I_a, I_b, etc., are the currents entering and leaving the junction. Currents ENTERING the junction are considered to be POSITIVE and currents LEAVING the junction are considered to be NEGATIVE. When solving a problem using Kirchhoff's current law, the currents must be placed into the equation WITH THE PROPER POLARITY SIGNS ATTACHED.

Example. Solve for the value of I_3 in figure 3-42.

Given: $I_1 = 10$ amps

$I_2 = 3$ amps

$I_4 = 5$ amps

Solution: $I_a + I_b + \ldots I_n = 0$

The currents are placed into the equation with the proper signs.

$$I_1 + I_2 + I_3 + I_4 = 0$$

$$10 \text{ amps} + (-3 \text{ amps}) + I_3 + (-5 \text{ amps}) = 0$$

$$I_3 + 2 \text{ amps} = 0$$

$$I_3 = -2 \text{ amps}$$

I_3 has a value of 2 amperes, and the negative sign shows it to be a current LEAVING the junction.

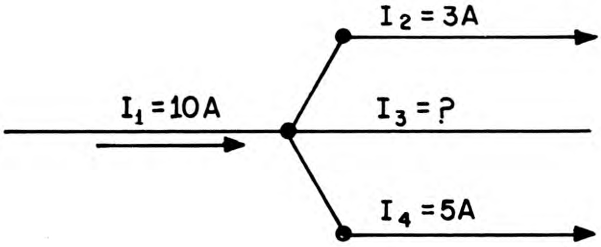


Figure 3-42.—Circuit for example problem.

Example. Using figure 3-43 solve for the magnitude and direction of I_3.

Given:

$I_1 = 6$ amps

$I_2 = 3$ amps

$I_4 = 5$ amps

Solution:

$$I_a + I_b + \ldots I_n = 0$$

$$I_1 + I_2 + I_3 + I_4 = 0$$

$$6 \text{ amps} + (-3 \text{ amps}) + I_3 + (-5 \text{ amps}) = 0$$

$$I_3 + (-2 \text{ amps}) = 0$$

$$I_3 = +2 \text{ amps}$$

I_3 is 2 amperes and its positive sign shows it to be a current entering the junction.

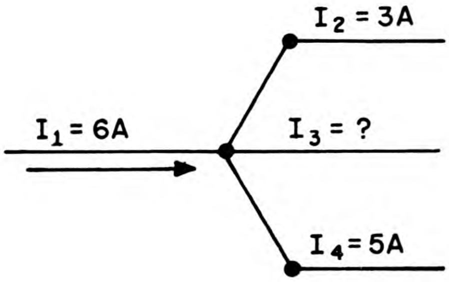


Figure 3-43.—Circuit for example problem.

Q34. There is a relationship between total current and current through the individual components in a circuit. What is this relationship in a series circuit and a parallel circuit?

Q35. In applying Kirchhoff's current law, what does the polarity of the current indicate?

Resistance in a Parallel Circuit

In the example diagram, figure 3-44, there are two resistors connected in parallel across a 5-volt battery. Each has a resistance value of 10 ohms. A complete circuit consisting of two parallel paths is formed and current flows as shown.

Computing the individual currents shows that there is one-half of an ampere of current through each resistance. The total current flowing from the battery to the junction of the resistors, and returning from the resistors to the battery, is equal to 1 ampere.

The total resistance of the circuit can be calculated by using the values of total voltage (E_T) and total current (I_T).

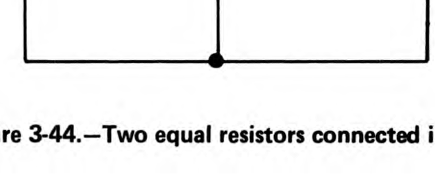


Figure 3-44.—Two equal resistors connected in parallel.

NOTE: From this point on the abbreviations and symbology for electrical quantities will be used in example problems.

Given: $E_T = 5\text{ V}$

$I_T = 1\text{ A}$

Solution: $R = \frac{E}{I}$

$$R_T = \frac{E_T}{I_T}$$

$$R_T = \frac{5\text{ V}}{1\text{ A}}$$

$$R_T = 5\ \Omega$$

This computation shows the total resistance to be 5 ohms; one-half the value of either of the two resistors.

Since the total resistance of a parallel circuit is smaller than any of the individual resistors, total resistance of a parallel circuit is not the sum of the individual resistor values as was the case in a series circuit. The total resistance of resistors in parallel is also referred to as EQUIVALENT RESISTANCE (R_{eq}). The terms total resistance and equivalent resistance are used interchangeably.

There are several methods used to determine the equivalent resistance of parallel circuits. The best method for a given circuit depends on the number and value of the resistors. For the circuit described above, where all resistors have the same value, the following simple equation is used:

$$R_{eq} = \frac{R}{N}$$

Where: R_{eq} = equivalent parallel resistance

R = ohmic value of one resistor

N = number of resistors

This equation is valid for any number of parallel resistors of EQUAL VALUE.

A34. Total current in a series circuit flows through every circuit component but in a parallel circuit total current divides among the available paths.

A35. Whether the current is entering the junction (+) or leaving the junction (-)

Example. Four 40-ohm resistors are connected in parallel. What is their equivalent resistance?

Given: $R_1 = R_2 = R_3 = R_4$

$R_1 = 40\ \Omega$

Solution: $R_{eq} = \frac{R}{N}$

$R_{eq} = \frac{40\ \Omega}{4}$

$R_{eq} = 10\ \Omega$

Figure 3-45 shows two resistors of unequal value in parallel. Since the total current is shown, the equivalent resistance can be calculated.

Given: $E_s = 30\ V$

$I_T = 15\ A$

Solution: $R_{eq} = \frac{E_s}{I_T}$

$R_{eq} = \frac{30\ V}{15\ A}$

$R_{eq} = 2\ \Omega$

The equivalent resistance of the circuit shown in figure 3-45 is smaller than either of the two resistors (R_1, R_2). An important point to remember is that the equivalent resistance of a parallel circuit is always less than the resistance of any branch.

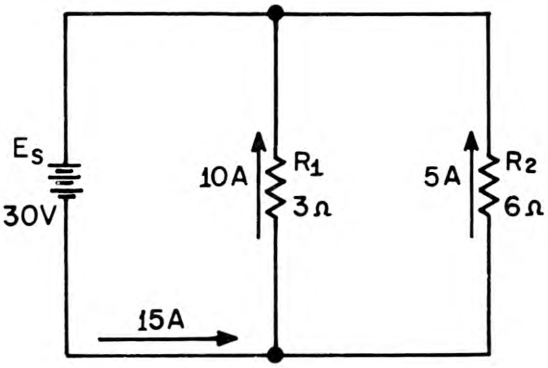


Figure 3-45.—Example circuit with unequal parallel resistors.

Equivalent resistance can be found if you know the individual resistance values and the source voltage. By calculating each branch current, adding the branch currents to calculate total current, and dividing the source voltage by the total current, the total can be found. This method, while effective, is somewhat lengthy. A quicker method of finding equivalent resistance is to use the general formula for resistors in parallel:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \frac{1}{R_n}$$

If you apply the general formula to the circuit shown in figure 3-45, you will get the same value for equivalent resistance (2Ω) as was obtained in the previous calculation that used source voltage and total current.

Given: $R_1 = 3\Omega$

$R_2 = 6\Omega$

Solution: $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$

$\frac{1}{R_{eq}} = \frac{1}{3\Omega} + \frac{1}{6\Omega}$

Convert the fractions to a common denominator.

$$\frac{1}{R_{eq}} = \frac{2}{6\Omega} + \frac{1}{6\Omega}$$

$$\frac{1}{R_{eq}} = \frac{3}{6\Omega}$$

$$\frac{1}{R_{eq}} = \frac{1}{2\Omega}$$

Since both sides are reciprocals, (divided into one) disregard the reciprocal function.

$$R_{eq} = 2\Omega$$

The formula you were given for equal resistors in parallel ($R_{eq} = \frac{R}{N}$) is a simplification of the general formula for resistors in parallel ($\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \frac{1}{R_n}$). There are other simplifications of the general formula for resistors in parallel which can be used to calculate the total or equivalent resistance in a parallel circuit.

RECIPROCAL METHOD.—This method is based upon taking the reciprocal of each side of the equation. This presents the general formula for resistors in parallel as:

$$R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \ldots \frac{1}{R_n}}$$

This formula is used to solve for the equivalent resistance of a number of unequal parallel resistors. You must find the lowest common denominator in solving these problems. If you are a little hazy on finding the lowest common denominator, brush up on it in *Mathematics Volume 1,* NAVEDTRA 10069 (Series).

Example: Three resistors are connected in parallel as shown in figure 3-46. The resistor values are: R_1 = 20 ohms, R_2 = 30 ohms, R_3 = 40 ohms. What is the equivalent resistance? (use the reciprocal method)

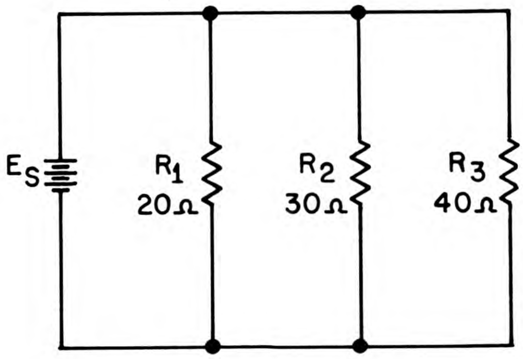


Figure 3-46.—Example parallel circuit with unequal branch resistors.

Given: $R_1 = 20\Omega$

$R_2 = 30\Omega$

$R_3 = 40\Omega$

Solution: $$R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

$$R_{eq} = \frac{1}{\frac{1}{20\Omega} + \frac{1}{30\Omega} + \frac{1}{40\Omega}}$$

$$R_{eq} = \frac{1}{\frac{6}{120\Omega} + \frac{4}{120\Omega} + \frac{3}{120\Omega}}$$

$$R_{eq} = \frac{1}{\frac{13}{120}\Omega}$$

$$R_{eq} = \frac{120}{13}\Omega$$

$$R_{eq} = 9.23\Omega$$

PRODUCT OVER THE SUM METHOD.–A convenient method for finding the equivalent, or total, resistance of two parallel resistors is by using the following formula.

$$R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2}$$

This equation, called the product over the sum formula, is used so frequently it should be committed to memory.

Example. What is the equivalent resistance of a 20-ohm and a 30-ohm resistor connected in parallel, as in figure 3-47?

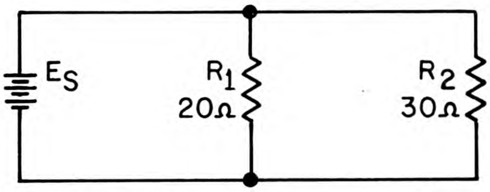


Figure 3-47.—Parallel circuit with two unequal resistors.

Given: $R_1 = 20$

$R_2 = 30$

Solution:

$$R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$R_{eq} = \frac{20\Omega \times 30\Omega}{20\Omega + 30\Omega}$$

$$R_{eq} = \frac{600}{50}\Omega$$

$$R_{eq} = 12\Omega$$

Q36. Four equal resistors are connected in parallel, each resistor has an ohmic value of 100 ohms, what is the equivalent resistance?

Q37. Three resistors connected in parallel have values of 12kΩ, 20kΩ, and 30kΩ. What is the equivalent resistance?

Q38. Two resistors connected in parallel have values of 10kΩ and 30kΩ. What is the equivalent resistance?

Power in a Parallel Circuit

Power computations in a parallel circuit are essentially the same as those used for the series circuit. Since power dissipation in resistors consists of a heat loss, power dissipations are additive regardless of how the resistors are connected in the circuit. The total power is equal to the sum of the power dissipated by the individual resistors. Like the series circuit, the total power consumed by the parallel circuit is:

$$P_T = P_1 + P_2 + \ldots P_n$$

Example. Find the total power consumed by the circuit in figure 3-48.

Given:

$R_1 = 10\Omega$

$I_{R1} = 5\text{ A}$

$R_2 = 25\Omega$

$I_{R2} = 2\text{ A}$

$R_3 = 50\Omega$

$I_{R3} = 1\text{ A}$

Solution:

$$P = I^2 R$$

$$P_{R1} = (I_{R1})^2 \times R_1$$

$$P_{R1} = (5\text{ A})^2 \times 10\Omega$$

$$P_{R1} = 250\text{ W}$$

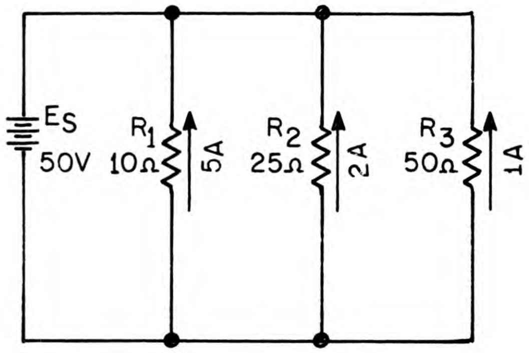


Figure 3-48.—Example parallel circuit.

$$P_{R2} = (I_{R2})^2 \times R_2$$

$$P_{R2} = (2\text{ A})^2 \times 25\Omega$$

$$P_{R2} = 100\text{ W}$$

$$P_{R3} = (I_{R3})^2 \times R_3$$

$$P_{R3} = (1\text{ A})^2 \times 50\Omega$$

$$P_{R3} = 50\text{ W}$$

$$P_T = P_{R1} + P_{R2} + P_{R3}$$

$$P_T = 250\text{ W} + 100\text{ W} + 50\text{ W}$$

$$P_T = 400\text{ W}$$

Since the total current and source voltage are known the total power can also be computed by:

Given: $E_s = 50\text{ V}$

$I_T = 8\text{ A}$

Solution: $P_T = E_s \times I_T$

$P_T = 50\text{ V} \times 8\text{ A}$

$P_T = 400\text{ W}$

Equivalent Circuits

In the study of electricity, it is often necessary to reduce a complex circuit into a simpler form. Any complex circuit consisting of resistances can be redrawn (reduced) to a basic equivalent circuit containing the voltage source and a single resistor representing total resistance. This process is called reduction to an EQUIVALENT CIRCUIT.

Figure 3-49 shows a parallel circuit with three resistors of equal value and the redrawn equivalent circuit. The parallel circuit shown in part A shows the original circuit. To create the equivalent circuit, you must first calculate the equivalent resistance.

Given: $R_1 = 45\Omega$

$R_2 = 45\Omega$

$R_3 = 45\Omega$

Solution: $R_{eq} = \frac{R}{N}$

$R_{eq} = \frac{45\Omega}{3}$

$R_{eq} = 15\Omega$

Once the equivalent resistance is known, a new circuit is drawn consisting of a single resistor (to represent the equivalent resistance) and the voltage source, as shown in part B.

Rules for Parallel D.C. Circuits

1. The same voltage exists across each branch of a parallel circuit and is equal to the source voltage.
2. The current through a branch of a parallel network is inversely proportional to the amount of resistance of the branch.
3. The total current of a parallel circuit is equal to the sum of the individual branch currents of the circuit.

A36. **25 ohms ($R_{eq} = \frac{R}{N}$)**

A37. 6 kΩ ($R_{eq} = \dfrac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$ **(use powers of ten.)**

A38. 7.5 kΩ ($R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2}$)

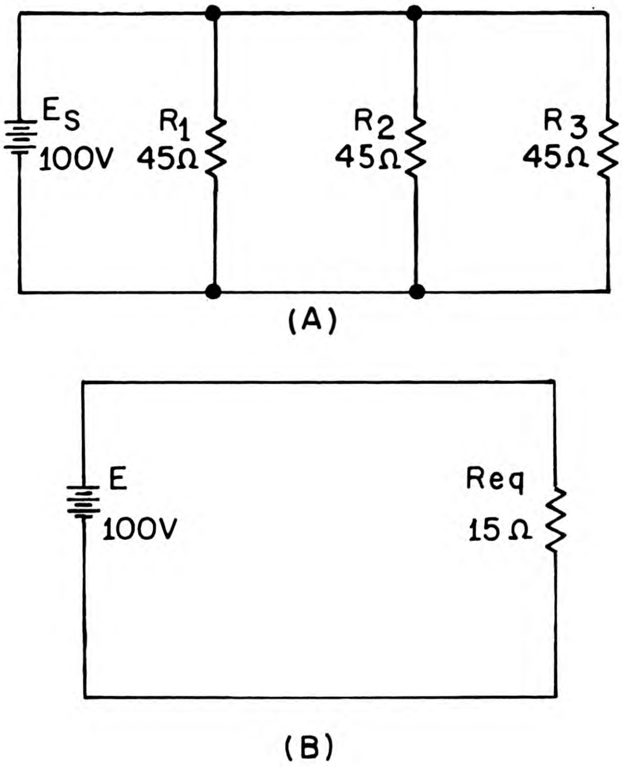


Figure 3-49.—Parallel circuit with equivalent circuit.

4. The total resistance of a parallel circuit is found by the general formula:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots \frac{1}{R_n}$$

or one of the formulas derived from this general formula.

5. The total power consumed in a parallel circuit is equal to the sum of the power consumptions of the individual resistances.

SOLVING PARALLEL CIRCUIT PROBLEMS

Problems involving the determination of resistance, voltage, current, and power in a parallel circuit are solved as simply as in a series circuit. The procedure is the same – (1) draw the circuit diagram, (2) state the values given and the values to be found, (3) select the equations to be used in solving for the unknown quantities based upon the known quantities, and (4) substitute the known values in the equation you have selected and solve for the unknown value.

Example: A parallel circuit consists of five resistors. The value of each resistor is known and the current through R_1 is known. You are asked to calculate the value for total resistance, total power, total current, source voltage, the power used by each resistor and the current through resistors R_2, R_3, R_4, and R_5.

Given:

$R_1 = 20\Omega$

$R_2 = 30\Omega$

$R_3 = 18\Omega$

$R_4 = 18\Omega$

$R_5 = 18\Omega$

$I_{R1} = 9$ A

Find: R_T, E_s, I_T, P_T, I_{R2}, I_{R3}, I_{R4}, I_{R5}, P_{R1}, P_{R2}, P_{R3}, P_{R4}, P_{R5}

This may appear to be a large amount of mathematical manipulation. However, if you use the step-by-step approach the circuit will fall apart quite easily.

The first step in solving this problem is for you to draw the circuit and indicate the known values as shown in figure 3-50.

There are several ways to approach this problem. With the values you have been given you could first solve for R_T, the power used by R_1, or the voltage across R_1 which you know is equal to the source voltage and the voltage across each of the other resistors. Solving for R_T or the power used by R_1 will not help in solving for the other unknown values.

Once the voltage across R_1 is known, this value will help you calculate other unknowns. Therefore the logical unknown to solve for is the source voltage (the voltage across R_1).

Given: $R_1 = 20\Omega$

$I_{R\,1} = 9\text{ A}$

$E_{R\,1} = E_s$

Solution: $E_s = R_1 \text{ x } I_{R\,1}$

$E_s = 9\text{ A x } 20\Omega$

$E_s = 180\text{ V}$

Now that source voltage is known you can solve for current in each branch.

Given: $E_s = 180\text{ V}$

$R_2 = 30\Omega$

$R_3 = 18\Omega$

$R_4 = 18\Omega$

$R_5 = 18\Omega$

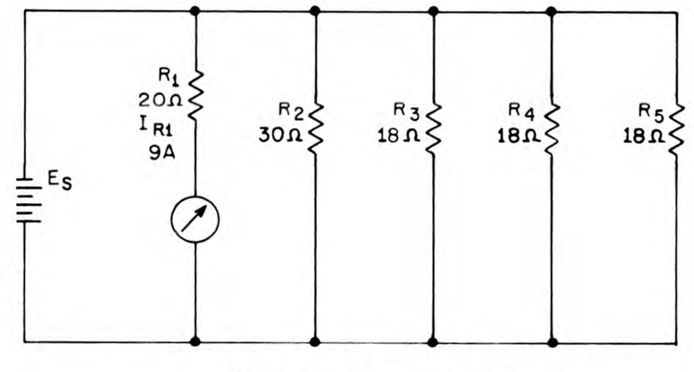


Figure 3-50.—Parallel circuit problem.

Solution:

$$I_{R\,2} = \frac{E_s}{R_2}$$

$$I_{R\,2} = \frac{180\text{ V}}{30\ \Omega}$$

$$I_{R\,2} = 6\text{ A}$$

$$I_{R\,3} = \frac{E_s}{R_3}$$

$$I_{R\,3} = \frac{180\text{ V}}{18\ \Omega}$$

$$I_{R\,3} = 10\text{ A}$$

Since $R_3 = R_4 = R_5$ and the voltage across each branch is the same:

$$I_{R\,4} = 10\text{ A}$$

$$I_{R\,5} = 10\text{ A}$$

Solving for total resistance.

Given: $R_1 = 20\Omega$

$R_2 = 30\Omega$

$R_3 = 18\Omega$

$R_4 = 18\Omega$

$R_5 = 18\Omega$

Solution:

$$R_T = R_{eq}$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5}$$

$$\frac{1}{R_T} = \frac{1}{20\Omega} + \frac{1}{30\Omega} + \frac{1}{18\Omega} + \frac{1}{18\Omega} + \frac{1}{18\Omega}$$

$$\frac{1}{R_T} = \frac{9 + 6 + 10 + 10 + 10\,\Omega}{180 \qquad \text{(LCD)}}$$

$$\frac{1}{R_T} = \frac{45\Omega}{180}$$

$$R_T = \frac{180}{45\Omega}$$

$$R_T = 4\Omega$$

An alternate method for solving for R_T can be used. By observation, you can see that R_3, R_4, and R_5 are of equal ohmic value. Therefore an equivalent resistor can be substituted for these three resistors in solving for total resistance.

Given: $R_3 = R_4 = R_5 = 18\Omega$

Solution: $R_{eq1} = \frac{R}{N}$

$$R_{eq1} = \frac{18\Omega}{3}$$

$$R_{eq1} = 6\Omega$$

The circuit can now be redrawn using a resistor labeled R_{eq1} in place of R_3, R_4, and R_5 as shown in figure 3-51.

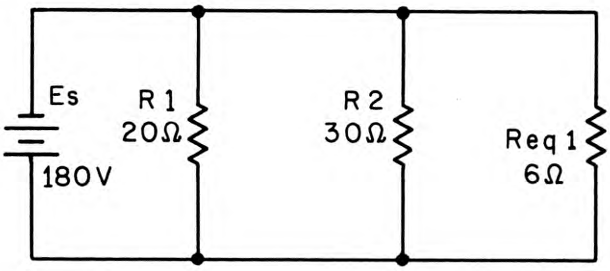


Figure 3-51.—First equivalent parallel circuit.

An equivalent resistor can be calculated and substituted for R_1 and R_2 by use of the product over the sum formula.

Given: $R_1 = 20\Omega$

$R_2 = 30\Omega$

Solution: $R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2}$

$$R_{eq2} = \frac{20\Omega \times 30\Omega}{20\Omega + 30\Omega}$$

$$R_{eq2} = \frac{600}{50}\Omega$$

$$R_{eq2} = 12\Omega$$

The circuit is now redrawn again using a resistor labeled R_{eq2} in place of R_1 and R_2 as shown in figure 3-52.

You are now left with two resistors in parallel. The product over the sum method can now be used to solve for total resistance.

Given: $R_{eq1} = 6\Omega$

$R_{eq2} = 12\Omega$

$$R_T = R_{eq}$$

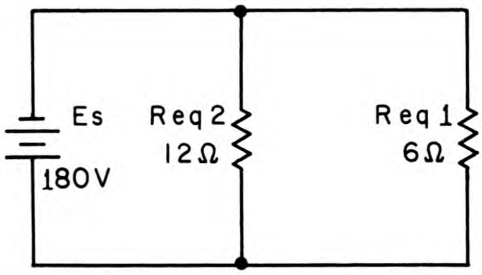


Figure 3-52.—Second equivalent parallel circuit.

Solution: $R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2}$

$R_T = \frac{R_{eq\,1} \times R_{eq\,2}}{R_{eq\,1} + R_{eq\,2}}$

$R_T = \frac{6\Omega \times 12\Omega}{6\Omega + 12\Omega}$

$R_T = \frac{72}{18}\Omega$

$R_T = 4\Omega$

This agrees with the solution found by using the general formula for solving for resistors in parallel.

The circuit can now be redrawn as shown in figure 3-53 and total current can be calculated.

Given: $E_s = 180$ V

$R_T = 4\Omega$

Solution: $I_T = \frac{E_s}{R_T}$

$I_T = \frac{180 \text{ V}}{4\Omega}$

$I_T = 45$ A

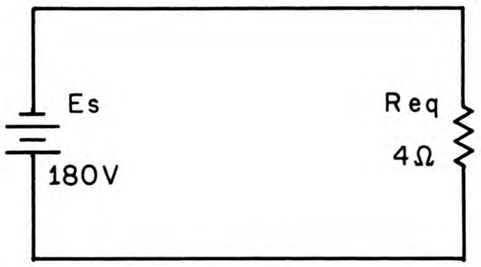


Figure 3-53.—Parallel circuit redrawn to final equivalent circuit.

This solution can be checked by using the values already calculated for the branch currents.

Given: $I_{R\,1} = 9$ A

$I_{R\,2} = 6$ A

$I_{R\,3} = 10$ A

$I_{R\,4} = 10$ A

$I_{R\,5} = 10$ A

Solution: $I_T = I_{R\,1} + I_{R\,2} + \ldots I_{R\,n}$

$I_T = 9 \text{ A} + 6 \text{ A} + 10 \text{ A} + 10 \text{ A} + 10 \text{ A}$

$I_T = 45$ A

Now that total current is known the next logical step is to find total power.

Given: $E_s = 180$ V

$I_T = 45$ A

Solution: $P = EI$

$P_T = E_s \times I_T$

$P_T = 180 \text{ V} \times 45 \text{ A}$

$P_T = 8100 \text{ Watts} = 8.1 \text{ kW}$

Solving for the power in each branch.

Given: $E_s = 180\ V$

$I_{R1} = 9\ A$

$I_{R2} = 6\ A$

$I_{R3} = 10\ A$

$I_{R4} = 10\ A$

$I_{R5} = 10\ A$

Solution: $P = EI$

$P_{R1} = E_s \times I_{R1}$

$P_{R1} = 180\ V \times 9\ A$

$P_{R1} = 1620\ W$

$P_{R2} = E_s \times I_{R2}$

$P_{R2} = 180\ V \times 6\ A$

$P_{R2} = 1080\ W$

$P_{R3} = E_s \times I_{R3}$

$P_{R3} = 180\ V \times 10\ A$

$P_{R3} = 1800\ W$

Since $I_{R3} = I_{R4} = I_{R5}$ then, $P_{R3} = P_{R4} = P_{R5} = 1800\ W$ The previous calculation for total power can now be checked.

Given: $P_{R1} = 1620\ W$

$P_{R2} = 1080\ W$

$P_{R3} = 1800\ W$

$P_{R4} = 1800\ W$

$P_{R5} = 1800\ W$

Solution:

$P_T = P_{R1} + P_{R2} + P_{R3} + P_{R4} + P_{R5}$

$P_T = 1620W + 1080W + 1800W + 1800W + 1800W$

$P_T = 8100W$

$P_T = 8.1kW$

Q39. What term identifies a single resistor that represents total resistance of a complex circuit?

Q40. The total power in both series and parallel circuits is computed with the formula: $P_T = P_1 + P_2 + P_3 + \ldots P_n$. Why can this formula be used for both series and parallel circuits?

Q41. A circuit consists of three resistors connected in parallel across a voltage source. $R_1 = 40\Omega$, $R_2 = 30\Omega$, $R_3 = 40\Omega$, and $P_{R3} = 360$ watts. Solve for R_T, E_s, and I_{R2}. (Hint: Draw and label the circuit first.)

SERIES-PARALLEL D.C. CIRCUITS

In the preceding discussions, series and parallel d.c. circuits have been considered separately. The technician will encounter circuits consisting of both series and parallel elements. A circuit of this type is referred to as a COMBINATION CIRCUIT. Solving for the quantities and elements in a combination circuit is simply a matter of applying the laws and rules discussed up to this point.

SOLVING COMBINATION-CIRCUIT PROBLEMS

The basic technique used for solving d.c. combination-circuit probems is the use of equivalent circuits. To simplify a complex circuit to a simple circuit containing only one load, equivalent circuits are substituted (on paper) for the complex circuit they represent.

To demonstrate the method used to solve combination circuits problems, the network shown in figure 3-54(A) will be used to calculate various circuit quantities, such as resistance, current, voltage, and power.

Examination of the circuit shows that the only quantity that can be computed with the given information is the equivalent resistance of R_2 and R_3.

Given: $R_2 = 20\Omega$

$R_3 = 30\Omega$

Solution: $R_{eq1} = \frac{R_2 \times R_3}{R_2 + R_3}$ (Product over the sum)

$$R_{eq1} = \frac{20\Omega \times 30\Omega}{20\Omega + 30\Omega}$$

$$R_{eq1} = \frac{600}{50}\Omega$$

$$R_{eq1} = 12\Omega$$

Now that the equivalent resistance for R_2 and R_3 has been calculated the circuit can be redrawn as a series circuit as shown in figure 3-54(B).

The equivalent resistance of this circuit (total resistance) can now be calculated.

Given: $R_1 = 8\Omega$ (Resistors in series)

$R_{eq1} = 12\Omega$

Solution: $R_{eq} = R_1 + R_{eq1}$

$$R_{eq} = 8\Omega + 12\Omega$$

$$R_{eq} = 20\Omega$$

or

$$R_T = 20\Omega$$

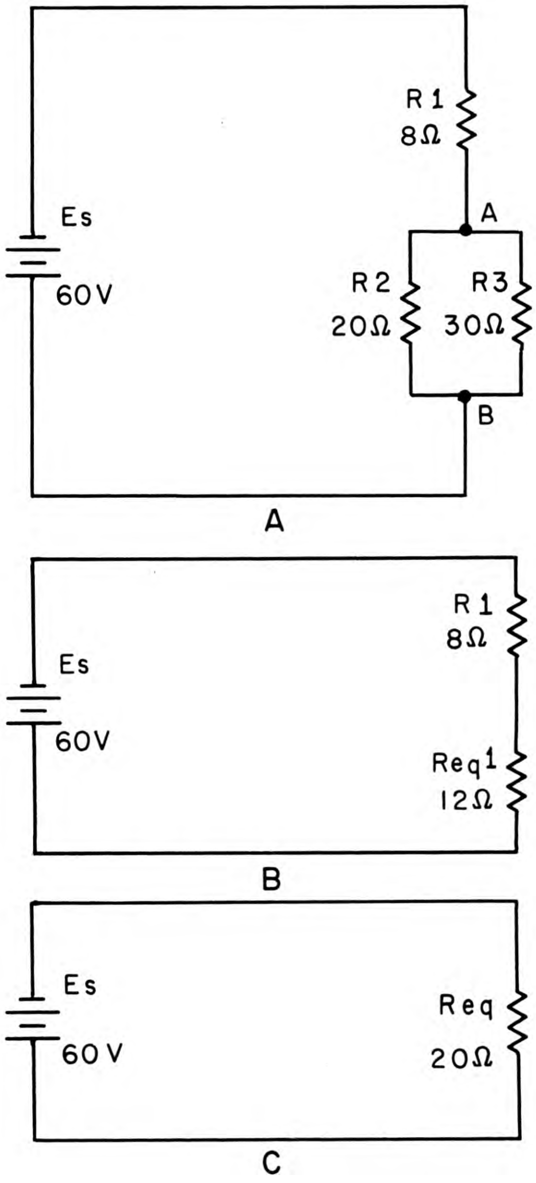


Figure 3-54.—Example combination circuit.

The original circuit can be redrawn with a single resistor that represents the equivalent resistance of the entire circuit as shown in figure 3-54(C).

To find total current in the circuit:

Given: $E_s = 60$ V

$R_T = 20\Omega$

A39. Equivalent resistor or R_{eq}

A40. In both cases all the power used in the circuit must come from the source

A41. $R_T = 12\Omega \quad (\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3})$

$E_S = 120\text{ V} \quad (E_S = E_{R3} = \sqrt{P_{R3} \times R_3})$

$I_{R2} = 4\text{ A} \quad (I_{R2} = \frac{E_S}{R_2})$

Solution: $I_T = \frac{E_s}{R_T}$

$I_T = \frac{60\text{ V}}{20\Omega}$ (Ohm's law)

$I_T = 3\text{ A}$

To find total power in the circuit:

Given: $E_s = 60\text{ V}$

$I_T = 3\text{ A}$

Solution: $P_T = E_s \times I_T$

$P_T = 60\text{ V} \times 3\text{ A}$

$P_T = 180\text{ W}$

To find the voltage dropped across R_1, R_2, and R_3 refer to figure 3-54(B). R_{eq1} represents the parallel network of R_2 and R_3. Since the voltage across each branch of a parallel circuit is equal, the voltage across R_{eq1} (E_{eq1}) will be equal to the voltage across R_2 (E_{R2}) and also equal to the voltage across R_3 (E_{R3}).

Given: $I_T = 3\text{ A}$

$R_1 = 8\Omega$

$R_{eq1} = 12\Omega$

(Current through each part of a series circuit is equal to total current.)

Solution: $E_{R1} = I_1 \times R_1$

$E_{R1} = 3\text{ A} \times 8\Omega$

$E_{R1} = 24\text{ V}$

$E_{R2} = E_{R3} = E_{eq1}$

$E_{eq1} = I_T \times R_{eq1}$

$E_{eq1} = 3\text{ A} \times 12\Omega$

$E_{eq1} = 36\text{ V}$

$E_{R2} = 36\text{ V}$

$E_{R3} = 36\text{ V}$

To find power used by R_1:

Given: $E_{R1} = 24\text{ V}$

$I_T = 3\text{ A}$

Solution: $P_{R1} = E_{R1} \times I_T$

$P_{R1} = 24\text{ V} \times 3\text{ A}$

$P_{R1} = 72\text{ W}$

To find the current through R_2 and R_3, refer to the original circuit, figure 3-54(A). You know E_{R2} and E_{R3} from previous calculation.

Given: $E_{R2} = 36\text{ V}$

$E_{R3} = 36\text{ V}$

$R_2 = 20\Omega$

$R_3 = 30\Omega$

Solution: $I_{R2} = \frac{E_{R2}}{R_2}$ (Ohm's law)

$I_{R2} = \frac{36\text{ V}}{20\ \Omega}$

$I_{R2} = 1.8\text{ A}$

$I_{R3} = \frac{E_{R3}}{R_3}$

$I_{R3} = \frac{36\text{ V}}{30\ \Omega}$

$I_{R3} = 1.2\text{ A}$

To find power used by R_2 and R_3, using values from previous calculations:

Given: $E_{R2} = 36\text{ V}$

$E_{R3} = 36\text{ V}$

$I_{R2} = 1.8\text{ A}$

$I_{R3} = 1.2\text{ A}$

Solution: $P_{R2} = E_{R2} \times I_{R2}$

$P_{R2} = 36\text{ V} \times 1.8\text{ A}$

$P_{R2} = 64.8\text{ W}$

$P_{R3} = E_{R3} \times I_{R3}$

$P_{R3} = 36\text{ V} \times 1.2\text{ A}$

$P_{R3} = 43.2\text{ W}$

Now that you have solved for the unknown quantities in this circuit, you can apply what you have learned to any series, parallel, or combination circuit. It is important to remember to first look at the circuit and from observation make your determination of the type of circuit, what is known, and what you are looking for. A minute spent in this manner may save you many unnecessary calculations.

Having computed all the currents and voltages of figure 3-54, a complete description of the operation of the circuit can be made. The total current of 3 amps leaves the negative terminal of the battery and flows through the 8-ohm resistor (R_1). In so doing, a voltage drop of 24 volts occurs across resistor R_1. At point A, this 3-ampere current divides into two currents. Of the total current, 1.8 amps flows through the 20-ohm resistor. The remaining current of 1.2 amps flows from point A, down through the 30-ohm resistor to point B. This current produces a voltage drop of 36 volts across the 30-ohm resistor. (Notice that the voltage drops across the 20- and 30-ohm resistors are the same.) The two branch currents of 1.8 and 1.2 amps combine at junction B and the total current of 3 amps flows back to the source. The action of the circuit has been completely described with the exception of power consumed, which could be described using the values previously computed.

It should be pointed out that the combination circuit is not difficult to solve. The key to its solution lies in knowing the order in which the steps of the solution must be accomplished.

Practice Circuit Problem

Figure 3-55 is a typical combination circuit. To make sure you understand the techniques of solving for the unknown quantities, solve for E_{R1}.

It is not necessary to solve for all the values in the circuit to compute the voltage drop across resistor R_1 (E_{R1}). First look at the circuit and determine that the values given do not provide enough information to solve for E_{R1} directly.

If the current through R_1 (I_{R1}) is known, then E_{R1} can be computed by applying the formula:

$$E_{R1} = R_1 \times I_{R1}$$

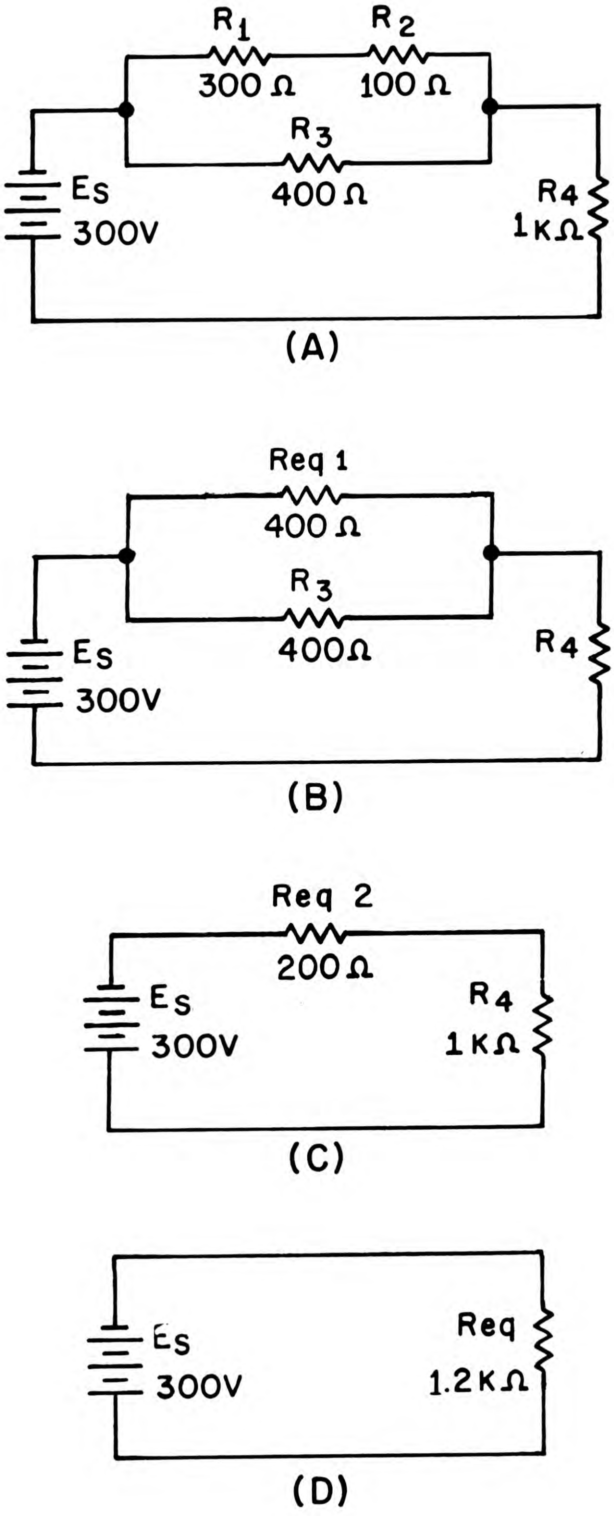

R1
R2
300 Ω
100 Ω
R3
400 Ω
Es
300V
R4
1KΩ
(A)
Req 1
400 Ω
R3
400Ω
Es
300V
R4
(B)
Req 2
200Ω
Es
300V
R4
1KΩ
(C)
Es
300V
Req
1.2KΩ
(D)

Figure 3-55.—Combination practice circuit.

The following steps will be used to solve the problem.

1. The total resistance (R_T) is calculated by the use of equivalent resistance.

Given: $R_1 = 300\Omega$

$R_2 = 100\Omega$

Solution: $R_{eq1} = R_1 + R_2$

$R_{eq1} = 300\Omega + 100\Omega$

$R_{eq1} = 400\Omega$

Redraw the circuit as shown in figure 3-55(B).

Given: $R_{eq1} = 400\Omega$

$R_3 = 400\Omega$

Solution: $R_{eq2} = \frac{R}{N}$ (Equal resistors in parallel.)

$R_{eq2} = \frac{400\Omega}{2}$

$R_{eq2} = 200\Omega$

Redraw the circuit as shown in figure 3-55(C).

Given: $R_{eq2} = 200\Omega$

$R_4 = 1\ k\Omega$

Solution: $R_{eq} = R_{eq2} + R_4$

$R_{eq} = 200\Omega + 1\ k\Omega$

$R_{eq} = 1.2\ k\Omega$

2. The total current (I_T) is now computed.

Given: $E_s = 300\ V$

$R_{eq} = 1.2\ k\Omega$

Solution: $I_T = \frac{E_s}{R_{eq}}$

$I_T = \frac{300\ V}{1.2\ k\Omega}$

$I_T = 250\ mA$

3. Solve for the voltage dropped across $R_{eq\,2}$. This represents the voltage dropped across the network R_1, R_2, and R_3 in the original circuit.

Given: $R_{eq\,2} = 200\Omega$

$I_T = 250\ mA$

Solution: $E_{R\,eq\,2} = R_{eq\,2} \times I_T$

$E_{R\,eq\,2} = 200\Omega \times 250\ mA$

$E_{R\,eq\,2} = 50\ V$

4. Solve for the current through $R_{eq\,1}$. ($R_{eq\,1}$ represents the network R_1 and R_2 in the original circuit.) Since the voltage across each branch of a parallel circuit is equal to the voltage across the equivalent resistor representing the circuit:

$E_{R\,eq\,2} = E_{R\,eq\,1}$

Given: $E_{R\,eq\,1} = 50\ V$

$R_{eq\,1} = 400\Omega$

Solution: $I_{R\,eq\,1} = \frac{E_{R\,eq\,1}}{R_{eq\,1}}$

$I_{R\,eq\,1} = \frac{50\ V}{400\Omega}$

$I_{R\,eq\,1} = 125\ mA$

5. Solve for the voltage dropped across R_1 (the quantity you were asked to find). Since $R_{eq\,1}$ represents the series network of R_1 and R_2 and total current flows through each resistor in a series circuit, $I_{R\,1}$ must equal $I_{R\,eq\,1}$.

Given: $I_{R\,1} = 125\ mA$

$R_1 = 300\Omega$

Solution: $E_{R\,1} = I_{R\,1} \times R_1$

$E_{R\,1} = 125\ mA \times 300\Omega$

$E_{R\,1} = 37.5\ V$

Q42. **Refer to figure 3-55(A). If the following resistors were replaced with the values indicated: $R_1 = 900\Omega$, $R_3 = 1k\Omega$, what is the total power in the circuit? What is $E_{R\,2}$?**

REDRAWING CIRCUITS FOR CLARITY

You will notice that the schematic diagrams you have been working with have shown parallel circuits drawn as neat square figures, with each branch easily identified.

In actual practice the wired circuits and more complex schematics are rarely laid out in this simple form. For this reason, it is important for you to recognize that circuits can be drawn in a variety of ways, and to learn some of the techniques for redrawing them into their simplified form. When a circuit is redrawn for clarity or to its simplest form the following steps are used.

1. Trace the current paths in the circuit.
2. Label the junctions in the circuit.
3. Recognize points which are at the same potential.
4. Visualize a rearrangement, “stretching” or “shrinking”, of connecting wires.
5. Redraw the circuit into simpler form (through stages if necessary).

A42. $P_T = 60$ W, $E_{R2} = 10$ V

To redraw any circuit, start at the source, and trace the path of current flow through the circuit. At points where the current divides, called JUNCTIONS, parallel branches begin. These junctions are key points of reference in any circuit and should be labeled as you find them. The wires in circuit schematics are assumed to have NO RESISTANCE and there is NO VOLTAGE drop along any wire. This means that any unbroken wire is at the same voltage all along its length, until it is interrupted by a resistor, battery, or some other circuit component. In redrawing a circuit, a wire can be "stretched" or "shrunk" as much as you like without changing any electrical characteristic of the circuit.

Figure 3-56(A) is a schematic of a circuit that is not drawn in the box-like fashion used in previous illustrations. To redraw this circuit, start at the voltage source and trace the path for current to the junction marked (a). At this junction the current divides into three paths. If you were to stretch the wire to show the three current paths, the circuit would appear as shown in figure 3-56(B).

While these circuits may appear to be different, the two drawings actually represent the same circuit. The drawing in figure 3-56(B) is the familiar box-like structure and may be easier to work with. Figure 3-57(A) is a schematic of a circuit shown in a box-like structure, but may be misleading. This circuit in reality is a series-parallel circuit that may be redrawn as shown in figure 3-57(B). The drawing in part (B) of the figure is a simpler

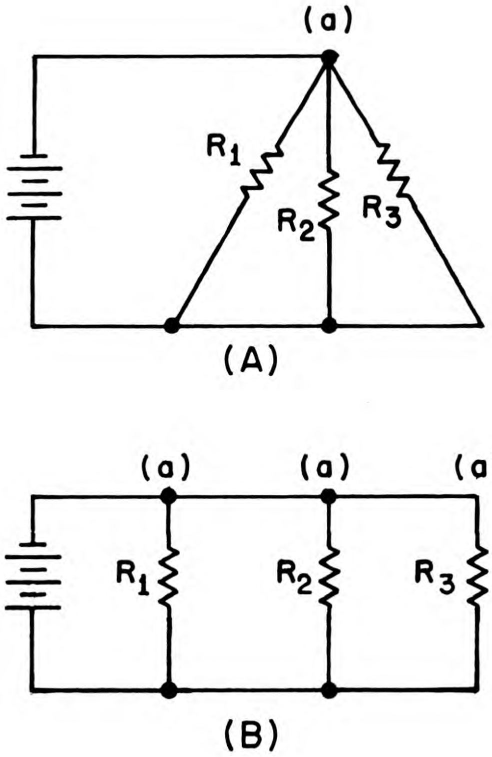


Figure 3-56.—Redrawing a simple parallel circuit.

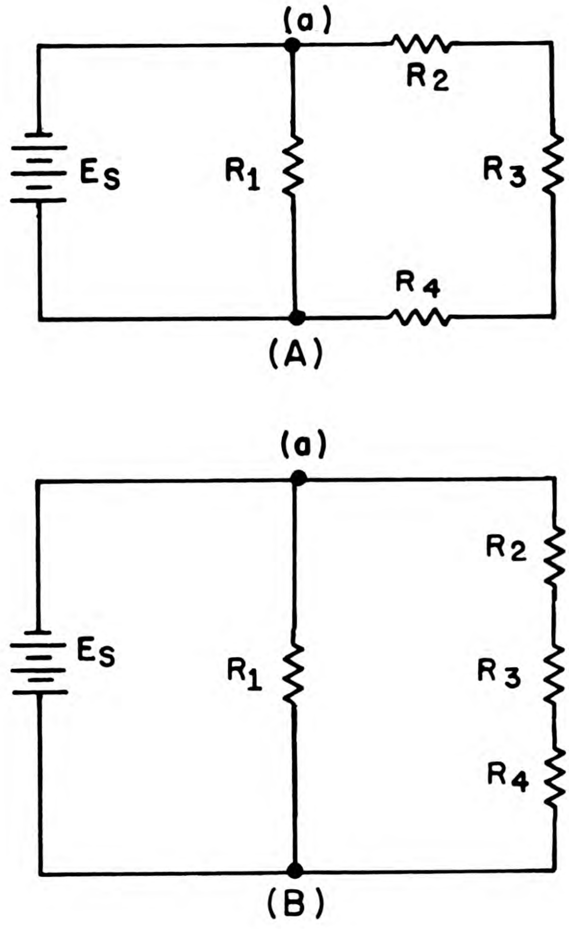


Figure 3-57.—Redrawing a simple series-parallel circuit.

representation of the original circuit and could be reduced to just two resistors in parallel.

Redrawing a Complex Circuit

Figure 3-58(A) shows a complex circuit that may be redrawn for clarification in the following steps.

NOTE: As you redraw the circuit, draw it in simple box-like form. Each time you reach a junction, a new branch is created by stretching or shrinking the wires.

Step 1. Start at the negative terminal of the voltage source. Current flows through R_1 to a junction and divides into three paths; label this junction (a). Follow one of the paths of current through R_2 and R_3 to a junction where the current divides into two more paths. This junction is labeled (b).

The current through one branch of this junction goes through R_5 and back to the source. (The most direct path.) Now that you have completed a path for current to the source, return to the last junction, (b). Follow current through the other branch from this junction. Current flows from junction (b) through R_4 to the source. All the paths from junction (b) have been traced. Only one path from junction (a) has been completed. You must now return to junction (a) to complete the other two paths. From junction (a) the current flows through R_7 back to the source. (There are no additional branches on this path.) Return to junction (a) to trace the third path from this junction. Current flows through R_6 and R_8 and comes to a junction. Label this junction (c). From junction (c) one path for current is through R_9 to the source. The other path for current from junction (c) is through R_{10} to the source. All the junctions in this circuit have now been labeled. The circuit and the junction can be redrawn as shown in figure 3-58(C). It is much easier to recognize the series and parallel paths in the redrawn circuit.

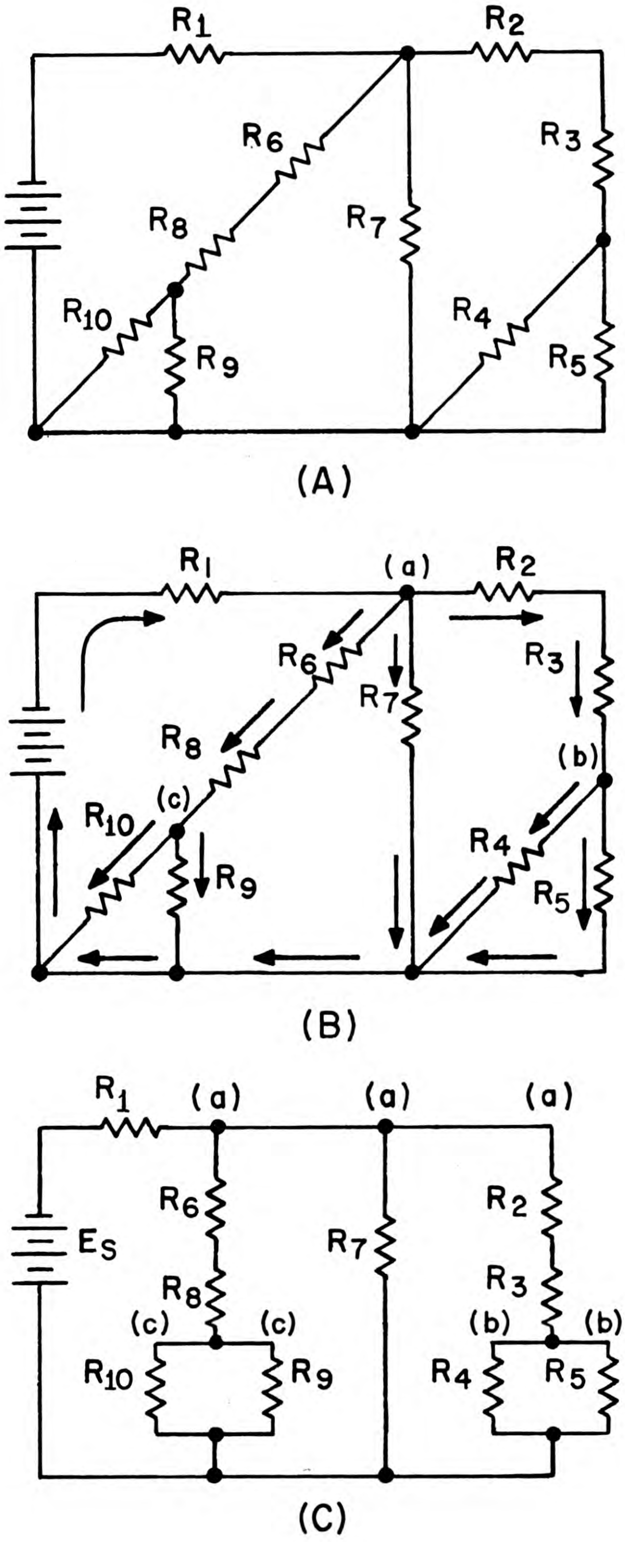


Figure 3-58.—Redrawing a complex circuit.

Q43. What is the total resistance of the circuit shown in figure 3-59? (Hint: Redraw the circuit to simplify and then use equivalent resistances to compute for R_T.)

Q44. What is the total resistance of the circuit shown in figure 3-60?

Q45. What effect does the internal resistance have on the rest of the circuit shown in figure 3-60?

EFFECTS OF OPEN AND SHORT CIRCUITS

Earlier in this topic the terms open and short circuits were discussed. The following discussion deals with the effects on a circuit when an open or a short occurs.

The major difference between an open in a parallel circuit and an open in a series circuit is that in the parallel circuit the open would not necessarily disable the circuit. If the open condition occurs in a series portion of the circuit, there will be no current because there is no complete path for current flow. If, on the other hand, the open occurs in a parallel path, some current will still flow in the circuit. The parallel branch where the open occurs will be effectively disabled, total resistance of the circuit will INCREASE and total current will DECREASE.

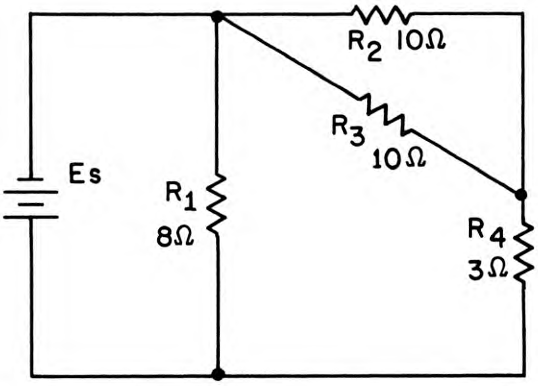


Figure 3-59.—Simplification circuit problem.

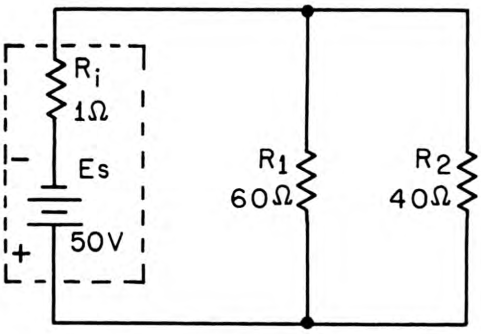


Figure 3-60.—Source resistance in a parallel circuit.

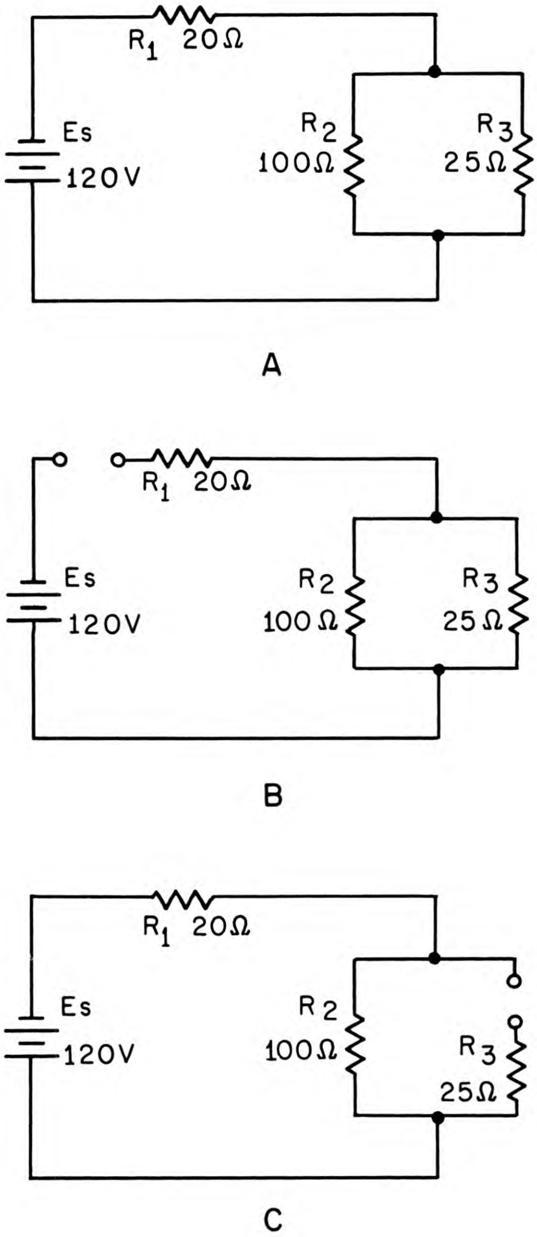
To clarify these points figure 3-61 illustrates a series-parallel circuit. First the effect of an open in the series portion of this circuit will be examined. Figure 3-61(A) shows the normal circuit, R_T = 40 ohms and I_T = 3 amps. In figure 3-61(B) an open is shown in the series portion of the circuit. There is no complete path for current, and the resistance of the circuit is considered to be infinite.

In figure 3-61(C) an open is shown in the parallel branch of R_3. There is no path for current through R_3. In the circuit, current flows through R_1 and R_2 only. Since there is only one path for current flow, R_1 and R_2 are effectively in series.

Under these conditions $R_T = 120\Omega$ and I_T = 1 amp. As you can see, when an open occurs in a parallel branch, total circuit resistance increases and total circuit current decreases.

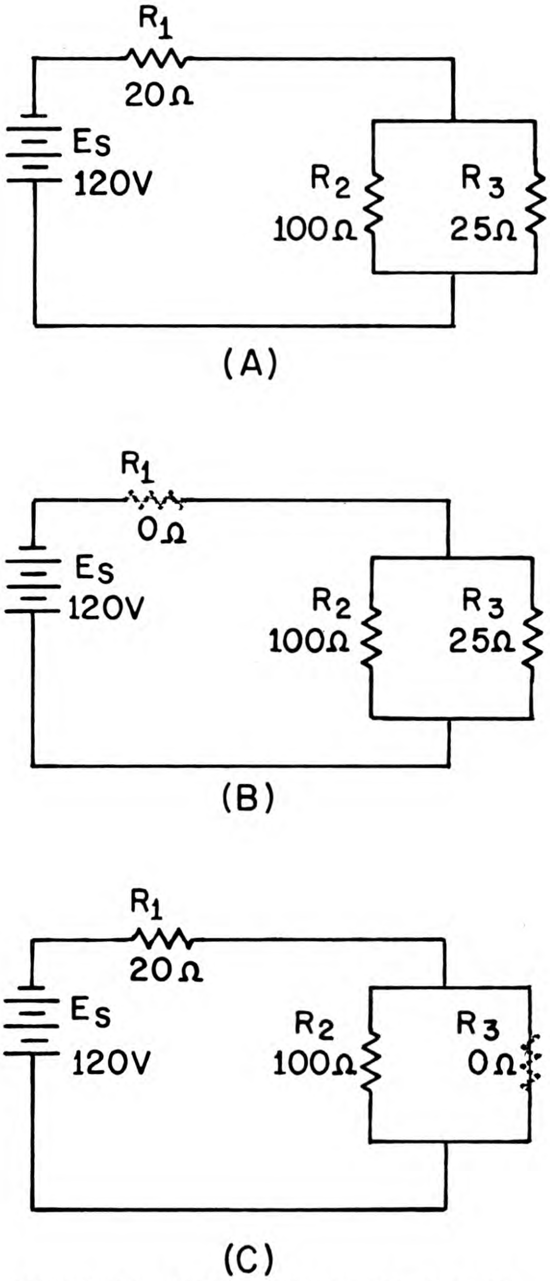
A short circuit in a parallel network has an effect similar to a short in a series circuit. In general, the short will cause an increase in current and the possibility of component damage regardless of the type of circuit involved. To illustrate this point, figure 3-62 shows a series-parallel network in which shorts are developed. In figure 3-62(A) the normal circuit is shown. R_T = 40 ohms and I_T = 3 amps.

In figure 3-62(B), R_1 has shorted. R_1 now has zero ohms of resistance. The total of the resistance of the circuit is now equal to the resistance of the parallel network of R_2 and R_3, or 20 ohms. Circuit current has increased to 6 amps. All of this current goes through the parallel network (R_2, R_3) and this increase in



R1 20Ω
Es
120V
R2
100Ω
R3
25Ω
A
R1 20Ω
Es
120V
R2
100 Ω
R3
25 Ω
B
R1 20Ω
Es
120V
R2
100Ω
R3
25Ω
C

Figure 3-61.—Series-parallel circuit with opens.



R1
20Ω
Es
120V
R2
100Ω
R3
25Ω
(A)
R1
0Ω
Es
120V
R2
100Ω
R3
25Ω
(B)
R1
20Ω
Es
120V
R2
100Ω
R3
0Ω
(C)

Figure 3-62.—Series-parallel circuit with shorts.

current would most likely damage the components.

In figure 3-62(C), R_3 has shorted. With R_3 shorted there is a short circuit in parallel with R_2. The short circuit routes the current around R_2, effectively removing R_2 from the circuit. Total circuit resistance is now equal to the resistance of R_1, or 20 ohms.

As you know, R_2 and R_3 form a parallel network. Resistance of the network can be calculated as follows:

Given: $R_2 = 100\Omega$

$R_3 = 0\Omega$

A43.	4Ω
A44.	25Ω
A45.	**Because of the 2 volt drop across the internal resistance, only 48 volts is available for the rest of the circuit**

Solution:

$$R_{eq} = \frac{R_2 \times R_3}{R_2 + R_3}$$

$$R_{eq} = \frac{100\Omega \times 0\Omega}{100\Omega + 0\Omega}$$

$$R_{eq} = 0\Omega$$

The total circuit current with R_3 shorted is 6 amps. All of this current flows through R_1 and would most likely damage R_1. Notice that even though only one portion of the parallel network was shorted, the entire parallel network was disabled.

Opens and shorts alike, if occurring in a circuit, result in an overall change in the equivalent resistance. This can cause undesirable effects in other parts of the circuit due to the corresponding change in the total current flow. A short usually causes components to fail in a circuit which is not properly fused or otherwise protected. The failure may take the form of a burned-out resistor, damaged source, or a fire in the circuit components and wiring.

Fuses and other circuit protection devices are installed in equipment circuits to prevent damage caused by increases in current. These circuit protection devices are designed to open if current increases to a predetermined value. Circuit protection devices are connected in series with the circuit or portion of the circuit that the device is protecting. When the circuit protection device opens, current flow ceases in the circuit.

A more thorough explanation of fuses and other circuit protection devices will be presented in Module 3, *Introduction to Circuit Protection, Control, and Measurement.*

Q46. **What is the effect on total resistance and total current in a circuit if an open occurs in (a) a parallel branch, and (b) in a series portion?**

Q47. **What is the effect on total resistance and total current in a circuit if a short occurs in (a) a parallel branch, and (b) in a series portion?**

Q48. **If one branch of a parallel network is shorted, what portion of circuit current flows through the remaining branches?**

VOLTAGE DIVIDERS

Most electrical and electronics equipment use voltages of various levels throughout their circuitry.

One circuit may require a 90 volt supply, another a 150 volt supply, and still another a 180 volt supply. These voltage requirements could be supplied by three individual power sources. This method is expensive and requires a considerable amount of room. The most common method of supplying these voltages is to use a single voltage source and a VOLTAGE DIVIDER. Before voltage dividers are explained, a review of what was discussed earlier concerning voltage references may be of help.

As you know, some circuits are designed to supply both positive and negative voltages. Perhaps now you wonder if a negative voltage has any less potential than a positive voltage. The answer is that 100 volts is 100 volts. Whether it is negative or positive does not affect the feeling you get when you are shocked.

Voltage polarities are considered as being positive or negative in respect to a reference point, usually ground. Figure 3-63 will help to illustrate this point.

Figure 3-63(A) shows a series circuit with a voltage source of 100 volts and four 50 ohm resistors connected in series. The ground, or reference point, is connected to one end of resistor R_1. The current in this circuit as determined by Ohm's law is .5 amp. Each resistor develops (drops) 25 volts. The five

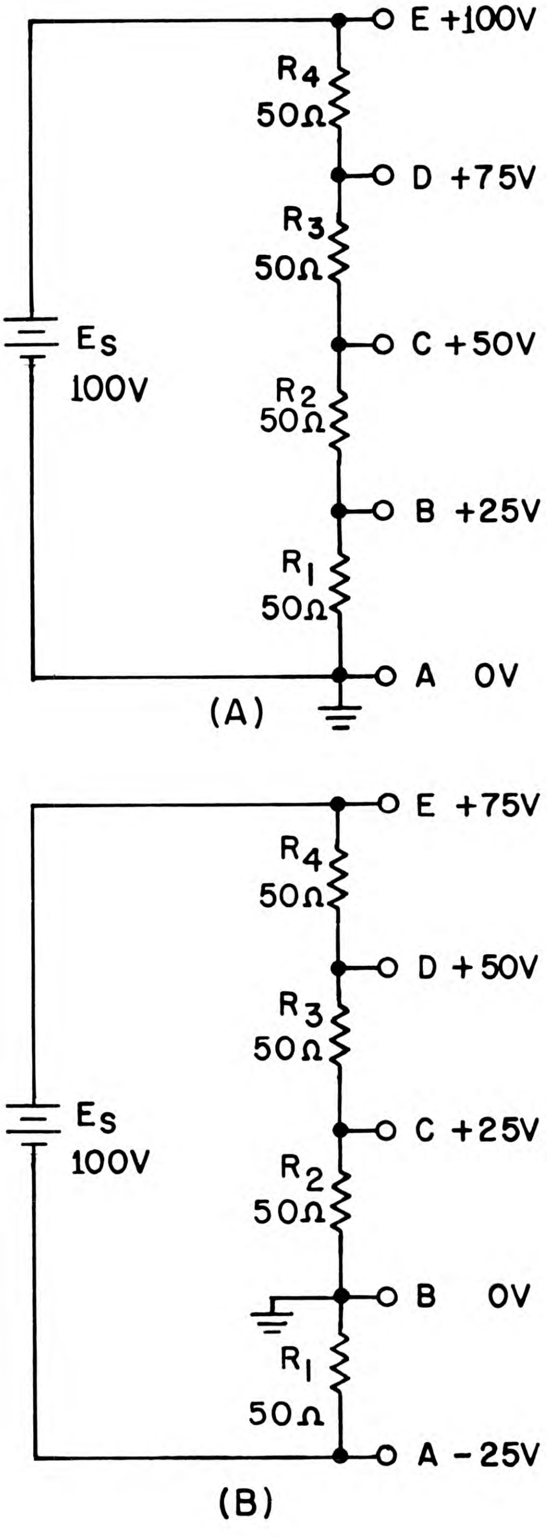


Figure 3-63.—Voltage polarities.

tap-off points indicated in the schematic are points at which the voltage can be measured. As indicated on the schematic, the voltage measured at each of the points from point A to point E starts at zero volts and becomes more positive in 25 volt steps to a value of positive 100 volts.

In figure 3-63(B), the ground, or reference point has been moved to point B. The current in the circuit is still .5 amp and each resistor still develops 25 volts. The total voltage developed in the circuit remains at 100 volts, but because the reference point has been changed, the voltage at point A is negative 25 volts. Point E, which was at positive 100 volts in figure 3-63(A), now has a voltage of positive 75 volts. As you can see the voltage at any point in the circuit is dependent on three factors; the current through the resistor, the ohmic value of the resistor, and the reference point in the circuit.

A typical voltage divider consists of two or more resistors connected in series across a source voltage (E_s). The source voltage must be as high or higher than any voltage developed by the voltage divider. As the source voltage is dropped in successive steps through the series resistors, any desired portion of the source voltage may be "tapped off" to supply individual voltage requirements. The values of the series resistors used in the voltage divider are determined by the voltage and current requirements of the loads.

Figure 3-64 is used to illustrate the development of a simple voltage divider. The requirement for this voltage divider is to provide a voltage of 25 volts and a current of 910 milliamps to the load from a source voltage of 100 volts. Figure 3-64(A) provides a circuit in which 25 volts is available at point B. If the load was connected between point B and ground you might think that the load would be supplied with 25 volts. This is not true since the load connected between point B and ground forms a parallel network of the load and resistor R_1. (Remember that the value of resistance of a parallel network is always less than the value of the smallest resistor in the network.)

Since the resistance of the network would now be less than 25 ohms, the voltage at point B would be less than 25 volts. This would not satisfy the requirement of the load.

A46. **(a) Total resistance increases, total current decreases**

(b) Total resistance becomes infinite, total current is equal to zero

A47. **(a) Total resistance decreases, total current increases**

(b) Total resistance decreases, total current increases

A48. **None**

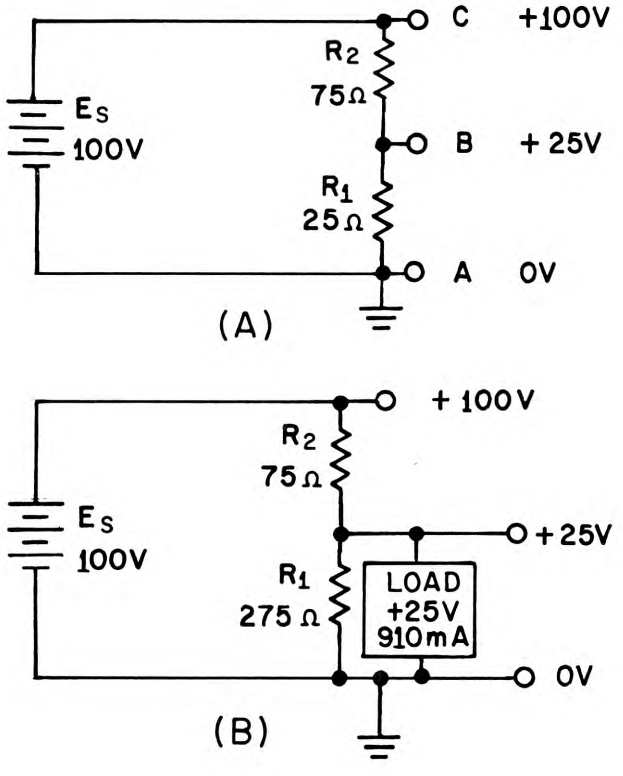


Figure 3-64.—Simple voltage divider.

To determine the size of resistor used in the voltage divider, a rule-of-thumb is used. The current in the divider resistor should equal approximately 10 percent of the load current. This current, which does not flow through any of the load devices, is called bleeder current.

Given this information, the voltage divider can be designed using the following steps.

1. Determine the load requirement and the available voltage source.

$$E_s = 100\text{ V}$$

$$E\text{ load} = 25\text{ V}$$

$$I\text{ load} = 910\text{ mA}$$

2. Select bleeder current by applying the 10% rule-of-thumb.

$$I_{R\,1} = 10\% \text{ x } I\text{ load}$$

$$I_{R\,1} = .1 \times 910\text{ mA}$$

$$I_{R\,1} = 91\text{ mA}$$

3. Calculate bleeder resistance.

$$R_1 = \frac{E_{R\,1}}{I_{R\,1}}$$

$$R_1 = \frac{25\text{ V}}{91\text{ mA}}$$

$$R_1 = 274.73\Omega$$

The value of R_1 may be rounded off to 275 ohms:

$$R_1 = 275\Omega$$

4. Calculate the total current (load plus bleeder).

$$I_T = I\text{ load} + I_{R\,1}$$

$$I_T = 910\text{ mA} + 91\text{ mA}$$

$$I_T = 1\text{ A (rounded off)}$$

5. Calculate the resistance of the other divider resistor(s).

$$E_{R2} = E_s - E_{R1}$$

$$E_{R2} = 100\ V - 25\ V$$

$$E_{R2} = 75\ V$$

$$R_2 = \frac{E_{R2}}{I_T}$$

$$R_2 = \frac{75\ V}{1\ A}$$

$$R_2 = 75\Omega$$

The voltage divider circuit can now be drawn as shown in figure 3-64(B).

Q49. What information must be known to determine the component values for a voltage divider?

Q50. If a voltage divider is required for a load that will use 450 mA of current, what should be the value of bleeder current?

Q51. If the load in question 50 requires a voltage of +90 V, what should be the value of the bleeder resistor?

Q52. If the source voltage for the voltage divider in question 50 supplies 150 volts, what is the total current through the voltage divider?

MULTIPLE-LOAD VOLTAGE DIVIDERS

A multiple-load voltage divider is shown in figure 3-65. An important point that was not emphasized before is that when using the 10% rule of thumb to calculate the bleeder current, you must take 10% of the total load current.

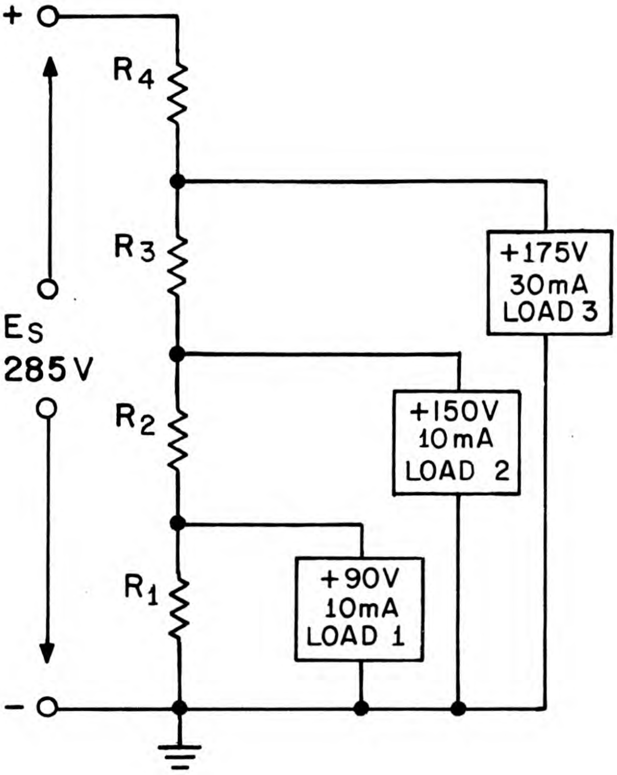


Figure 3-65.—Multiple-load voltage divider.

Given the information shown in figure 3-65, you can calculate the values for the resistors needed in the voltage-divider circuits. The same steps will be followed as in the previous voltage divider problem.

Given: Load 1: E = 90 V

I = 10 mA

Load 2: E = 150 V

I = 10 mA

Load 3: E = 175 V

I = 30 mA

E_s = 285 V

A49. The source voltage and load requirements (voltage and current).

A50. 45 mA (Rule-of-thumb)

A51. 2 kΩ

A52. 495 mA

The bleeder current should be 10% of the total load current.

Solution:

$I_{R1} = 10\% \times I \text{ (load total)}$

$I_{R1} = 10\% \times (10 \text{ mA} + 10 \text{ mA} + 30 \text{ mA})$

$I_{R1} = 5 \text{ mA}$

Since the voltage across R_1 (E_{R1}) is equal to the voltage requirement for load 1, Ohm's law can be used to calculate the value for R_1.

Solution: $R_1 = \frac{E_{R1}}{I_{R1}}$

$R_1 = \frac{90 \text{ V}}{5 \text{ mA}}$

$R_1 = 18 \text{ k}\Omega$

The current through R_2 (I_{R2}) is equal to the current through R_1 plus the current through load 1.

Solution: $I_{R2} = I_{R1} + I \text{ load } 1$

$I_{R2} = 5 \text{ mA} + 10 \text{ mA}$

$I_{R2} = 15 \text{ mA}$

The voltage across R_2 (E_{R2}) is equal to the difference between the voltage requirements of load 1 and load 2.

Solution: $E_{R2} = E \text{ load } 2 - E \text{ load } 1$

$E_{R2} = 150 \text{ V} - 90 \text{ V}$

$E_{R2} = 60 \text{ V}$

Ohm's law can now be used to solve for the value of R_2.

Solution: $R_2 = \frac{E_{R2}}{I_{R2}}$

$R_2 = \frac{60 \text{ V}}{15 \text{ mA}}$

$R_2 = 4 \text{ k}\Omega$

The current through R_3 (I_{R3}) is equal to the current through R_2 plus the current through load 2.

Solution: $I_{R3} = I_{R2} + I \text{ load } 2$

$I_{R3} = 15 \text{ mA} + 10 \text{ mA}$

$I_{R3} = 25 \text{ mA}$

The voltage across R_3 (E_{R3}) equals the difference between the voltage requirement of load 3 and load 2.

Solution: $E_{R3} = E \text{ load } 3 - E \text{ load } 2$

$E_{R3} = 175 \text{ V} - 150 \text{ V}$

$E_{R3} = 25 \text{ V}$

Ohm's law can now be used to solve for the value of R_3.

Solution:

$$R_3 = \frac{E_{R\,3}}{I_{R\,3}}$$

$$R_3 = \frac{25\text{ V}}{25\text{ mA}}$$

$$R_3 = 1\text{ k}\Omega$$

The current through R_4 ($I_{R\,4}$) is equal to the current through R_3 plus the current through load 3. $I_{R\,4}$ is equal to total circuit current (I_T).

Solution:

$$I_{R\,4} = I_{R\,3} + I\text{ load }3$$

$$I_{R\,4} = 25\text{ mA} + 30\text{ mA}$$

$$I_{R\,4} = 55\text{ mA}$$

The voltage across R_4 ($E_{R\,4}$) equals the difference between the source voltage and the voltage requirement of load 3.

Solution:

$$E_{R\,4} = E_s - E\text{ load }3$$

$$E_{R\,4} = 285\text{ V} - 175\text{ V}$$

$$E_{R\,4} = 110\text{ V}$$

Ohm's law can now be used to solve for the value of R_4.

Solution:

$$R_4 = \frac{E_{R\,4}}{I_{R\,4}}$$

$$R_4 = \frac{110\text{ V}}{55\text{ mA}}$$

$$R_4 = 2\text{ k}\Omega$$

With the calculations just explained, the values of the resistors used in the voltage divider are as follows:

$$R_1 = 18\text{ k}\Omega$$

$$R_2 = 4\text{ k}\Omega$$

$$R_3 = 1\text{ k}\Omega$$

$$R_4 = 2\text{ k}\Omega$$

POWER IN THE VOLTAGE DIVIDER

Power in the voltage divider is an extremely important quantity. The power dissipated by the resistors in the voltage divider should be calculated to determine the power handling requirements of the resistors. Total power of the circuit is needed to determine the power requirement of the source.

The power for the circuit shown in figure 3-65 is calculated as follows:

Given:

$$E_{R\,1} = 90\text{ V}$$

$$I_{R\,1} = 5\text{ mA}$$

Solution:

$$P_{R\,1} = E_{R\,1} \times I_{R\,1}$$

$$P_{R\,1} = 90\text{ V} \times 5\text{ mA}$$

$$P_{R\,1} = .45\text{ W}$$

The power in each resistor is calculated just as for R_1. When the calculations are performed the following results are obtained:

$$P_{R\,2} = .9\text{W}$$

$$P_{R\,3} = .625\text{ W}$$

$$P_{R\,4} = 6.05\text{ W}$$

To calculate the power for load 1:

Given: E load 1 = 90 V

I load 1 = 10 mA

Solution: P load 1 = E load 1 x I load 1

P load 1 = 90 V x 10 mA

P load 1 = .9 W

The power in each load is calculated just as for load 1. When the calculations are performed the following results are obtained.

P load 2 = 1.5 W

P load 3 = 5.25 W

Total power is calculated by summing the power consumed by the loads and the power dissipated by the divider resistors. The total power in the circuit is 15.675 watts.

The power used by the loads and divider resistors is supplied by the source. This applies to all electrical circuits; power for all components is supplied by the source.

Since power is the product of voltage and current, the power supplied by the source is equal to the source voltage multiplied by the total circuit current (E_s x I_T).

In the circuit of figure 3-65 the total power can be calculated by:

Given: $E_s = 285$ V

$I_T = 55$ mA (I_{R4})

Solution: $P_T = E_s \times I_T$

$P_T = 285$ V x 55 mA

$P_T = 15.675$ W

VOLTAGE DIVIDER WITH POSITIVE AND NEGATIVE VOLTAGE REQUIREMENTS

In many cases the load for a voltage divider requires both positive and negative voltages. Positive and negative voltages can be supplied from a single source voltage by connecting the ground (reference point) between two of the divider resistors. The exact point in the circuit at which the reference point is placed depends upon the voltages required by the loads.

For example, a voltage divider can be designed to provide the voltage and current to three loads from a given source voltage.

Given:

Load 1: E = -25 V

I = 300 mA

Load 2: E = +50 V

I = 50 mA

Load 3: E = +250 V

I = 100 mA

$E_s = 310$ V

The circuit is drawn as shown in figure 3-66. Notice the placement of the ground reference point. The values for resistor R_1, R_3, and R_4 are computed exactly as was done in the last example. I_{R1} is the bleeder current and can be calculated as follows:

Solution:

I_{R1} = 10% x I load total

I_{R1} = 10% x (300 mA + 50 mA + 100 mA)

I_{R1} = 45 mA

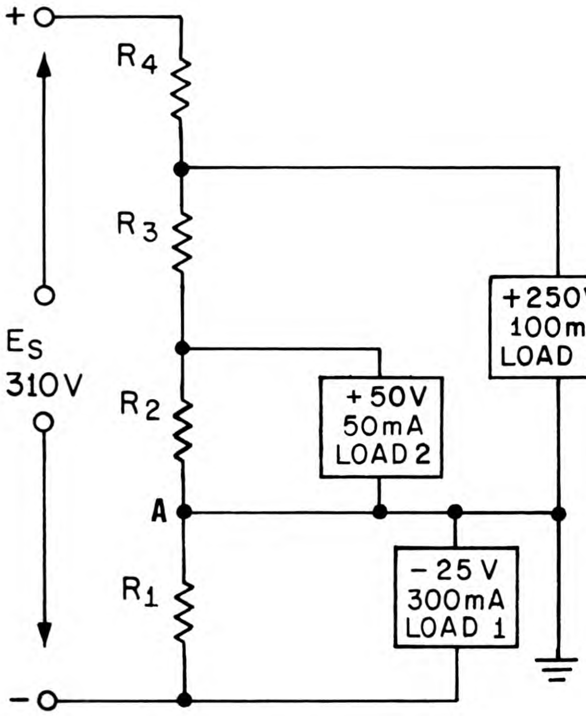


Figure 3-66.—Voltage divider providing both positive and negative voltages.

Calculate the value of R_1.

Solution: $R_1 = \frac{E_{R\,1}}{I_{R\,1}}$

$R_1 = \frac{25\text{ V}}{45\text{ mA}}$

$R_1 = 556\Omega$

Calculate the current through R_2 using Kirchoff's current law.

At point A:

$I_{R\,1} + I\text{ load }1 + I_{R\,2} + I\text{ load }2 + I\text{ load }3 = 0$

$45\text{ mA} + 300\text{ mA} + I_{R\,2} - 50\text{ mA} - 100\text{ mA} = 0$

$345\text{ mA} + I_{R\,2} - 150\text{ mA} = 0$

$195\text{ mA} + I_{R\,2} = 0$

$I_{R\,2} = -195\text{ mA}$

(or 195 mA leaving point A)

Since $E_{R\,2} = E\text{ load }2$, you can calculate the value of R_2.

Solution: $R_2 = \frac{E_{R\,2}}{I_{R\,2}}$

$R_2 = \frac{50\text{ V}}{195\text{ mA}}$

$R_2 = 256\Omega$

Calculate the current through R_3.

Solution: $I_{R\,3} = I_{R\,2} + I\text{ load }2$

$I_{R\,3} = 195\text{ mA} + 50\text{ mA}$

$I_{R\,3} = 245\text{ mA}$

The voltage across R_3 ($E_{R\,3}$) equals the difference between the voltage requirement of load 3 and load 2.

Solution: $E_{R\,3} = E\text{ load }3 - E\text{ load }2$

$E_{R\,3} = 250\text{ V} - 50\text{ V}$

$E_{R\,3} = 200\text{ V}$

Calculate the value of R_3.

Solution: $R_3 = \frac{E_{R\,3}}{I_{R\,3}}$

$R_3 = \frac{200\text{ V}}{245\text{ mA}}$

$R_3 = 816\Omega$

Calculate the current through R_4.

Solution: $I_{R\,4} = I_{R\,3} + I\text{ load }3$

$I_{R\,4} = 245\text{ mA} + 100\text{ mA}$

$I_{R\,4} = 345\text{ mA}$

The voltage across $E_{R\,4}$ equals the source voltage (E_s) minus the voltage requirement of load 3 and the voltage requirement of load 1. Remember Kirchhoff's voltage law which states that the sum of the voltage drops and emfs around any closed loop is equal to zero.

Solution: $E_{R4} = E_s - E\text{ load }3 - E\text{ load }1$

$E_{R4} = 310\text{ V} - 250\text{ V} - 25\text{ V}$

$E_{R4} = 35\text{ V}$

Calculate the value of R_4.

Solution: $R_4 = \frac{E_{R4}}{I_{R4}}$

$R_4 = \frac{35\text{ V}}{345\text{ mA}}$

$R_4 = 101.4\Omega$

With the calculations just explained, the values of the resistor used in the voltage divider are as follows:

$R_1 = 556\Omega$

$R_2 = 256\Omega$

$R_3 = 816\Omega$

$R_4 = 101\Omega$

From the information just calculated, any other circuit quantity, such as power, total current, or resistance of the load, could be calculated.

PRACTICAL APPLICATION OF VOLTAGE DIVIDERS

In actual practice the computed value of the bleeder resistor does not always come out to an even value. Since the rule-of-thumb for bleeder current is only an estimated value, the bleeder resistor can be of a value close to the computed value. (If the computed value of the resistance was 510 ohms, a 500 ohm resistor could be used.) Once the actual value of the bleeder resistor is selected, the bleeder current must be recomputed. The voltage developed by the bleeder resistor must be equal to the voltage requirement of the load in parallel with the bleeder resistor.

The value of the remaining resistors in the voltage divider is computed from the current through the remaining resistors and the voltage across them. These values must be used to provide the required voltage and current to the loads.

If the computed values for the divider resistors are not even values; series, parallel, or series-parallel networks can be used to provide the required resistance.

Example: A voltage divider is required to supply two loads from a 190.5 volts source. Load 1 requires +45 volts and 210 milliamps; load 2 requires +165 volts and 100 milliamps.

Calculate the bleeder current using the rule-of-thumb.

Given: $I\text{ load }1 = 210\text{ mA}$

$I\text{ load }2 = 100\text{ mA}$

Solution: $I_{R1} = 10\% \times (210\text{ mA} + 100\text{ mA})$

$I_{R1} = 31\text{ mA}$

Calculate the ohmic value of the bleeder resistor.

Given: $E_{R1} = 45\text{ V}$ (E load 1)

$I_{R1} = 31\text{ mA}$

Solution: $R_1 = \frac{E_{R1}}{I_{R1}}$

$R_1 = \frac{45\text{ V}}{31\text{ mA}}$

$R_1 = 1451.6\Omega$

Since it would be difficult to find a resistor of 1451.6 ohms, a practical choice for R_1 is 1500 ohms.

Calculate the actual bleeder current using the selected value for R_1.

Given: $E_{R1} = 45V$

$R_1 = 1.5k\Omega$

Solution: $I_{R1} = \frac{E_{R1}}{R_1}$

$I_{R1} = \frac{45\ V}{1.5\ k\Omega}$

$I_{R1} = 30\ mA$

Using this value for I_{R1}, calculate the resistance needed for the next divider resistor. The current (I_{R2}) is equal to the bleeder current plus the current used by load 1.

Given: $I_{R1} = 30\ mA$

$I\ load\ 1 = 210\ mA$

Solution: $I_{R2} = I_{R1} + I\ load\ 1$

$I_{R2} = 30\ mA + 210\ mA$

$I_{R2} = 240\ mA$

The voltage across R_2 (E_{R2}) is equal to the difference between the voltage requirement of load 2 and load 1, or 120 volts.

Calculate the value of R_2.

Given: $E_{R2} = 120\ V$

$I_{R2} = 240\ mA$

Solution: $R_2 = \frac{E_{R2}}{I_{R2}}$

$R_2 = \frac{120\ V}{240\ mA}$

$R_2 = 500\Omega$

The value of the final divider resistor is calculated with I_{R3} (I_{R2} + I load 2) equal to 340 mA and E_{R3} (E_s - E load 2) equal to 25.5V.

Given: $E_{R3} = 25.5\ V$

$I_{R3} = 340\ mA$

Solution: $R_3 = \frac{E_{R3}}{I_{R3}}$

$R_3 = \frac{25.5\ V}{340\ mA}$

$R_3 = 75\Omega$

A 75 ohm resistor may not be easily obtainable, so a network of resistors equal to 75 ohms can be used in place of R_3.

Any combination of resistor values adding up to 75 ohms could be placed in series to develop the required network. For example, if you had two 37.5 ohm resistors, you could connect them in series to get a network of 75 ohms. One 50 ohm and one 25 ohm resistor or seven 10 ohm and one 5 ohm resistor could also be used.

A parallel network could be constructed from two 150 ohm resistors or three 225 ohm resistors. Either of these parallel networks would also be a network of 75 ohms.

The network used in this example will be a series-parallel network using three 50 ohm resistors.

With the information given, you should be able to draw this voltage divider network.

Once the values for the various divider resistors have been selected, you can compute the power used by each resistor using the methods previously explained. When the power used by each resistor is known, the wattage rating required of each resistor determines the physical size and type needed for the circuit. This circuit is shown in figure 3-67.

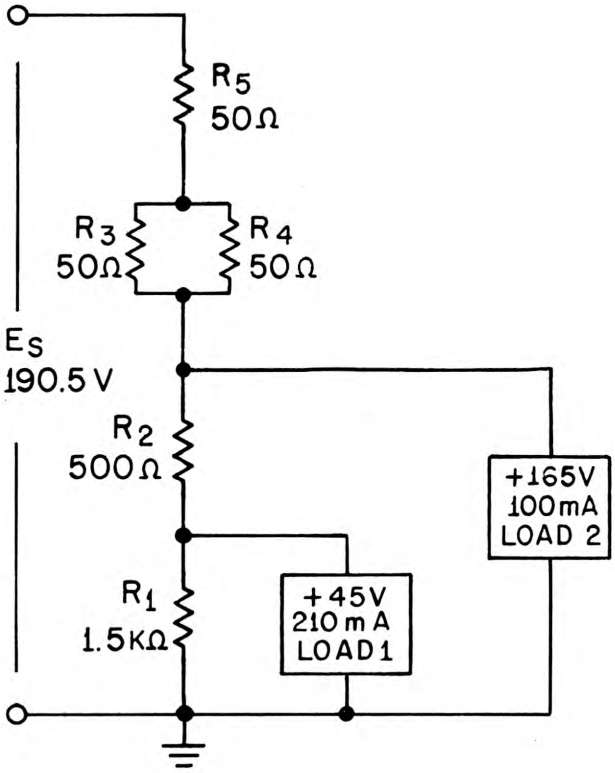


Figure 3-67.—Practical example of a voltage divider.

Q53. In figure 3-67, why is the value of R_1 calculated first?

Q54. In figure 3-67, how is (a) the current through R_2 and (b) the voltage drop across R_2 computed?

Q55. In figure 3-67, what is the power dissipated in R_1?

Q56. In figure 3-67, what is the purpose of the series-parallel network R_3, R_4, and R_5?

Q57. In figure 3-67, what should be the minimum wattage ratings of R_3 and R_5?

Q58. If the load requirement consists of both positive and negative voltages, what technique is used in the voltage divider to supply the loads from a single voltage source?

EQUIVALENT CIRCUIT TECHNIQUES

The circuit solutions that you have studied up to this point have been obtained mainly through the use of formulas derived from Ohm's law. As in many other fields of science, electricity has its share of special shortcut methods. Some of the special circuit analysis techniques are; THEVENIN'S THEOREM, which uses a process of circuit reduction to Thevenin's equivalent circuit, and NORTON'S THEOREM which is reduction of a circuit to Norton's equivalent. Another method is called LOOP ANALYSIS. This uses Kirchhoff's voltage law to simultaneously solve problems in parallel branches of a circuit. The use of these methods should be reserved until you have become thoroughly familiar with the methods covered thus far in this topic. You may want to explore some of the special techniques later in your career.

ELECTRICAL SAFETY

Safety precautions must always be observed by persons working around electric circuits and equipment to avoid injury from electric shock. Detailed safety precautions are contained in NAVMAT P-5100, SAFETY PRECAUTIONS FOR SHORE ACTIVITIES and OPNAVINST 5100-19, NAVY SAFETY PRECAUTIONS FOR FORCES AFLOAT.

The danger of shock from a 450-volt a.c. electrical service system is well recognized by operating personnel. This is shown by the relatively low number of reports of serious shock received from this voltage, despite its widespread use. On the other hand, a number of fatalities have been reported due to contact with low-voltage circuits. Despite a fairly widespread, but totally unfounded, popular belief to the contrary, low-voltage circuits (115 volts and below) are very dangerous and can cause death when the resistance of the body is lowered. Fundamentally, current, rather than voltage, is the measure of shock intensity. The passage of even a very small current through a vital part of the human body can cause DEATH. The voltage necessary to produce the fatal current is dependent upon the resistance of the body, contact conditions, the path through the body, etc. For example, when a 60-hertz alternating current, is passed through a human body from hand to hand or from hand to foot, and the current is gradually increased, it will cause the following effects: At about 1 milliampere (0.001 ampere) the shock can be felt; at about 10 milliamperes (0.01 ampere) the shock is of sufficient intensity to prevent voluntary control of the muscles; and at about 100 milliamperes (0.1 ampere) the shock is fatal if it lasts for 1 second or more. The above figures are the results of numerous investigations and are approximate because individuals differ in their resistance to electrical shock. It is most important to recognize that the resistance of the human body cannot be relied upon to prevent a fatal shock from 115 volts or less–FATALITIES FROM VOLTAGES AS LOW AS 30 VOLTS HAVE BEEN RECORDED. Tests have shown that body resistance under unfavorable conditions may be as low as 300 ohms, and possibly as low as 100 ohms from temple to temple if the skin is broken.

Conditions aboard ship add to the chance of receiving an electrical shock. Aboard ship the body is likely to be in contact with the metal structure of the ship and the body resistance may be low because of perspiration or damp clothing. Extra care and awareness of electrical hazards aboard ship are needed.

Short circuits can be caused by accidentally placing or dropping a metal tool, rule, flashlight case, or other conducting article across an energized line. The arc and fire which result, even on relatively low-voltage circuits, may cause extensive damage to equipment and serious injury to personnel.

Since ship service power distribution systems are designed to be ungrounded, many persons believe it is safe to touch one conductor, since no electrical current would flow. This is not true, since the distribution system is not totally isolated from the hull of the ship. If one conductor of an ungrounded electrical system is touched while the body is in contact with the hull of the ship or other metal equipment enclosure, a fatal electric current may pass through the body. ALL LIVE ELECTRIC CIRCUITS SHALL BE TREATED AS POTENTIAL HAZARDS AT ALL TIMES.

DANGER SIGNALS

Personnel should constantly be on the alert for any signs or indications which might indicate a malfunction of electric equipment. Besides the more obvious visual signs, the reaction of other senses, such as hearing, smell, and touch, should also make you aware of possible electrical malfunctions. Examples of signs which you must be alert for are: fire, smoke, sparks, arcing, or an unusual sound from an electric motor. Frayed and damaged cords or plugs; receptacles, plugs, and cords which feel warm to the touch; slight shocks felt when handling electrical equipment; unusually hot running electric motors and other electrical equipment; an odor of burning or overheated insulation; electrical equipment which either fails to operate or operates irregularly; and electrical equipment which produces excessive vibrations are also indications of malfunctions. When any of the above signs are noted, they are to be reported immediately to a qualified technician. DO NOT DELAY. Do not operate faulty equipment. Above all, do not attempt to make any repairs yourself if you are not qualified to do so. Stand clear of any suspected hazard and instruct others to do likewise.

- Warning Signs–They have been placed for your protection. To disregard them is to invite personal injury as well as possible damage to equipment. Switches and receptacles with a temporary warning tag, indicating work is being performed, are not to be touched.

- Working Near Electrical Equipment–When work must be performed in the immediate vicinity of electrical equipment, check with the technician responsible for the maintenance of the equipment so you can avoid

A53. **R_1 is the bleeder resistor. Bleeder current must be known before any of the remaining divider resistor ohmic values can be computed.**

A54. **(a) By adding the bleeder current ($I_{R\,1}$) and the current through load 1**

(b) By subtracting the voltage of load 1 from the voltage of load 2

A55. **1.35 watts**

A56. **The series-parallel network drops the remaining source voltage and is used to take the place of a single resistor (75 ohms) when the required ohmic value is not available in a single resistor.**

A57. **R_3 = 2 watts R_5 = 6 watts**

A58. **The ground (reference point) is placed in the proper point in the voltage divider so that positive and negative voltages are supplied.**

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any potential hazards of which you may not be immediately aware.

- Authorized Personnel Only—Because of the danger of fire, damage to equipment, and injury to personnel, all repair and maintenance work on electrical equipment shall be done only by authorized persons. Keep your hands off of all equipment which you have not been specifically authorized to handle. Particularly stay clear of electrical equipment opened for inspection, testing, or servicing.

- Circuit Breakers and Fuses—Covers for all fuse boxes, junction boxes, switch boxes, and wiring accessories should be kept closed. Any cover which is not closed or is missing should be reported to the technician responsible for its maintenance. Failure to do so may result in injury to personnel or damage to equipment in the event accidental contact is made with exposed live circuits.

ELECTRICAL FIRES

Carbon dioxide (CO_2) is used in fighting electrical fires. It is nonconductive and, therefore, the safest to use in terms of electrical safety. It also offers the least likelihood of damaging equipment. However, if the discharge horn of a CO_2 extinguisher is allowed to accidentally touch an energized circuit, the horn may transmit a shock to the person handling the extinguisher.

The very qualities which cause CO_2 to be a valuable extinguishing agent also make it dangerous to life. When it replaces oxygen in the air to the extent that combustion cannot be sustained, respiration also cannot be sustained. Exposure of a person to an atmosphere of high concentration of CO_2 will cause suffocation.

FIRST AID FOR ELECTRIC SHOCK

A person who has stopped breathing is not necessarily dead, but is in immediate danger. Life is dependent upon oxygen, which is breathed into the lungs and then carried by the blood to every body cell. Since body cells cannot store oxygen, and since the blood can hold only a limited amount (and that only for a short time), death will surely result from continued lack of breathing.

However, the heart may continue to beat for some time after breathing has stopped, and the blood may still be circulated to the body cells. Since the blood will, for a short time, contain a small supply of oxygen, the body cells will not die immediately. For a very few minutes, there is some chance that the person's life may be saved.

The process by which a person who has stopped breathing can be saved is called ARTIFICAL VENTILATION (RESPIRATION).

The purpose of artificial ventilation is to force air out of the lungs and into the lungs, in rhythmic alternation, until natural breathing is reestablished. Artificial ventilation should be given only when natural breathing has stopped; it should NOT be given to any person who is breathing naturally. You should not assume that an individual who is unconscious due to electrical shock has stopped breathing. To tell if someone suffering from an electrical shock is breathing, place your hands on the person's sides, at the level of the lowest ribs. If the victim is breathing, you will usually be able to feel the movement. Remember: DO NOT GIVE ARTIFICIAL VENTILATION TO A PERSON WHO IS BREATHING NATURALLY. Records show that seven out of ten victims of electric shock were revived when artificial respiration was started in less than 3 minutes. After 3 minutes, the chances of revival decrease rapidly.

Once it has been determined that breathing has stopped, the person nearest the victim should start the artificial ventilation without delay and send others for assistance and medical aid. The only logical, permissible delay is that required to free the victim from contact with the electricity in the quickest, safest way. This step, while it must be taken quickly, must be done with great care; otherwise, there may be two victims instead of one. In the case of portable electric tools, lights, appliances, equipment, or portable outlet extensions, this should be done by turning off the supply switch or by removing the plug from its receptacle. If the switch or receptacle cannot be quickly located, the suspected electrical device may be pulled free of the victim. Other persons arriving on the scene must be clearly warned not to touch the suspected equipment until it is deenergized. Aid should be enlisted to unplug the device as soon as possible. The injured person should be pulled free of contact with stationary equipment (such as a bus bar) if the equipment cannot be quickly deenergized, or if considerations of military operation or unit survival prevent immediate shutdown of the circuits.

This can be done quickly and safely by carefully applying the following procedures:

(a) Protect yourself with dry insulating material.

(b) Use a dry board, belt, clothing, or other available nonconductive material to free the victim from electrical contact. DO NOT TOUCH THE VICTIM UNTIL THE SOURCE OF ELECTRICITY HAS BEEN REMOVED.

Once the victim has been removed from the electrical source it should be determined if the person is breathing. If the person is not breathing a method of artificial ventilation is used.

Sometimes victims of electrical shock suffer cardiac arrest (heart stoppage) as well as loss of breathing. Artificial ventilation alone is not enough in cases where the heart has stopped. A technique known as Cardio-pulminary Resuscitation (CPR) has been developed to provide aid to a person who has stopped breathing and suffered a cardiac arrest. Because you most likely will be working in the field of electricity, the risk of electrical shock is higher than most other Navy occupations. You should, at your earliest opportunity, learn the technique of CPR.

CPR is relatively easy to learn and is taught in courses available from the American Red Cross, some Navy Medical Departments, and in the *Navy Standard First Aid Training Course* (NAVEDTRA 10081-D).

Q59. Is it considered safe for a person to touch any energized low-voltage conductor with the bare hand?

Q60. What should you do if you become aware of a possible malfunction in a piece of electrical equipment?

Q61. Who should perform CPR?

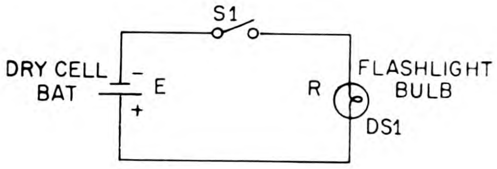
A59. **NEVER! All energized electric circuits should be considered potentially dangerous.**

A60. **You should immediately report this condition to a qualified technician.**

A61. **Only trained, qualified personnel**

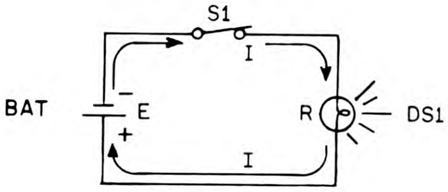
SUMMARY OF TOPIC 3

With the completion of this topic you have gained a basic understanding of d.c. circuits. The information you have learned will provide you with a firm foundation for continuing your study of electricity. The following is a summary of the important points in the topic.


S1
DRY CELL
BAT
-
+
E
R
FLASHLIGHT
BULB
DS1

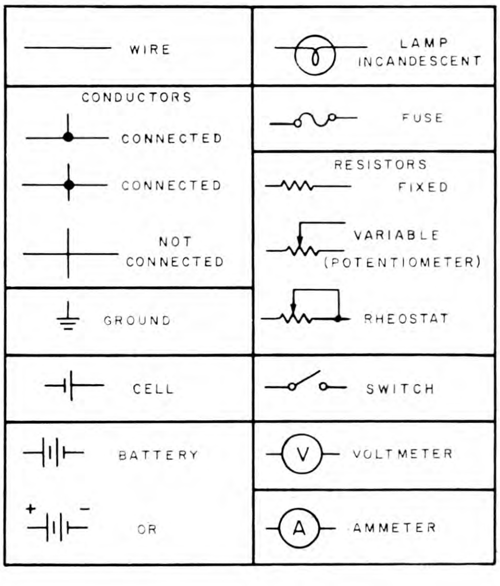
(A) DEENERGIZED

A BASIC ELECTRIC CIRCUIT consists of a source of electrical energy connected to a load. The load uses the energy and changes it to a useful form.


S1
I
BAT
-
E
+
R
DS1
I

(B) ENERGIZED

A SCHEMATIC DIAGRAM is a "picture" of a circuit, which uses symbols to represent components. The space required to depict an electrical or electronic circuit is greatly reduced by the use of a schematic.

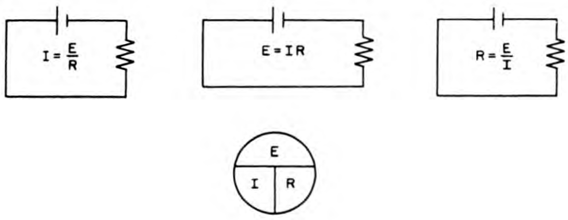

WIRE
LAMP
INCANDESCENT
CONDUCTORS
CONNECTED
FUSE
RESISTORS
CONNECTED
FIXED
NOT
CONNECTED
VARIABLE
(POTENTIOMETER)
GROUND
RHEOSTAT
CELL
SWITCH
BATTERY
V
VOLTMETER
+
-
OR
A
AMMETER

VOLTAGE (E) is the electrical force or pressure operating in a circuit.

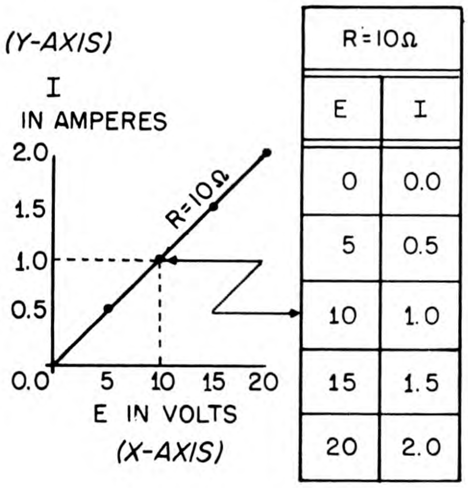
AN AMPERE (A) represents the current flow produced by one volt working across one ohm of resistance.

RESISTANCE (R) is the opposition to current. It is measured in ohms (Ω). One ohm of resistance will limit the current produced by one volt to a level of one ampere.

THE OHM'S FORMULA can be transposed to find one of the values in a circuit if the other two values are known. You can transpose the Ohm's law formula $I = \frac{E}{R}$ mathematically, or you can use the Ohm's law figure to determine the mathematical relationship between R, E, and I.



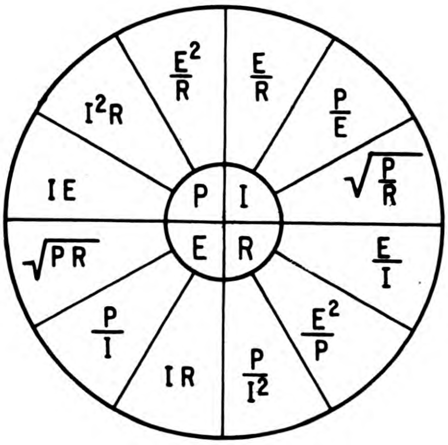
GRAPHICAL ANALYSIS of the relationship between R, E, and I can be studied by plotting these quantities on a graph. Such a graph is useful for observing the characteristics of an electrical device.



R=10Ω	
E	I
0	0.0
5	0.5
10	1.0
15	1.5
20	2.0

POWER is the rate of doing work per unit of time. The time required to perform a given amount of work will determine the power expended. As a formula, P = E X I, where P = power in watts, E = voltage in volts, and I = current in amperes.

THE FOUR BASIC ELECTRICAL QUANTITIES are P, I, E, R. Any single unknown quantity can be expressed in terms of any two of the other known quantities. The formula wheel is a simple representation of these relationships.



POWER RATING in watts indicates the rate at which a device converts electrical energy into another form of energy. The power rating of a resistor indicates the maximum power the resistor can withstand without being destroyed.

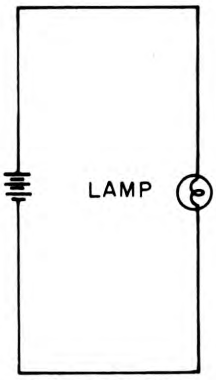
POWER USED by an electrical device is measured in watt-hours. One watt-hour is equal to one watt used continuously for one hour.

THE EFFICIENCY of an electrical device is equal to the electrical power converted into useful energy divided by the electrical power supplied to the device.

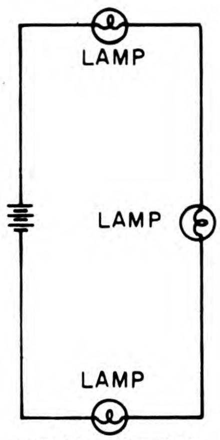
$$\text{EFF} = \frac{\text{Power converted}}{\text{Power used}}$$

HORSEPOWER is a unit of measurement often used to rate electrical motors. It is a unit of work. One horsepower is equal to 746 watts.

A SERIES CIRCUIT is defined as a circuit that has only one path for current flow.



BASIC CIRCUIT



SERIES CIRCUIT

RULES FOR SERIES D.C. CIRCUITS:

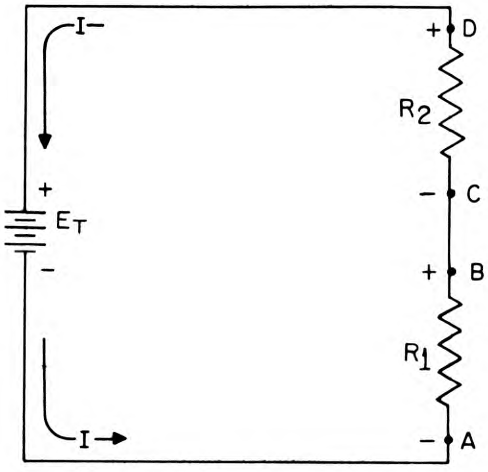
- The same current flows through each part of a series circuit.

- The total resistance of a series circuit is equal to the sum of the individual resistances.

- The total voltage across a series circuit is equal to the sum of the individual voltage drops.

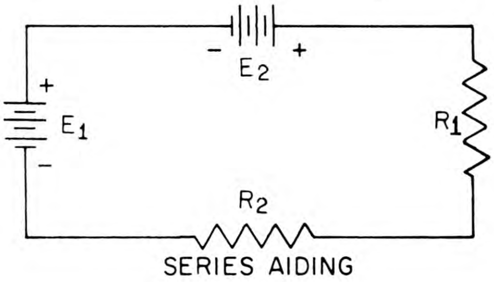
- The voltage drop across a resistor in a series circuit is proportional to the ohmic value of the resistor.

- The total power in a series circuit is equal to the sum of the individual power used by each circuit component.

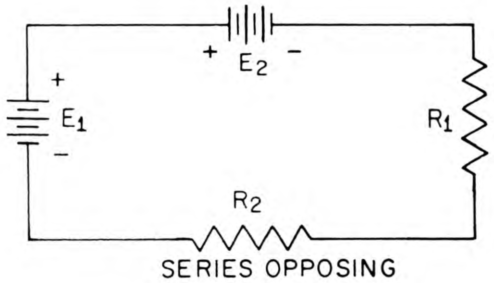


KIRCHHOFF'S VOLTAGE law states: The algebraic sum of the voltage drops in any closed path in a circuit and the electromotive forces in that path is equal to zero, or $E_a + E_b + E_c + \ldots E_n = 0$

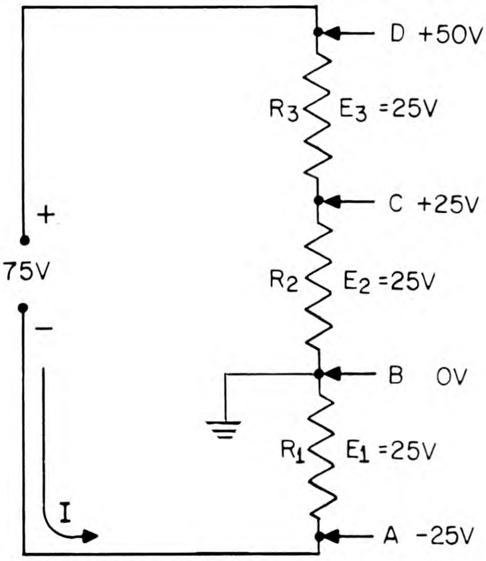
VOLTAGE POLARITIES must be used when applying Kirchhoff's voltage law. The point at which current enters a load (resistor) is considered negative with respective to the point at which current leaves the load.


E2
+
-
+
E1
-
R1
R2
SERIES AIDING

SERIES AIDING VOLTAGES cause current to flow in the same direction; thus the voltages are added.


+
E2
-
+
E1
-
R1
R2
SERIES OPPOSING

SERIES OPPOSING VOLTAGES tend to force current to flow in opposite directions; thus the equivalent voltage is the difference between the opposing voltages.

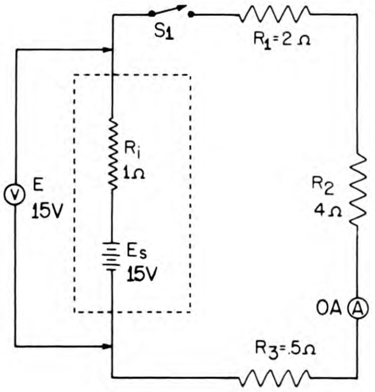

D +50V
R3
E3 =25V
C +25V
+
75V
-
R2
E2 =25V
B 0V
R1
E1 =25V
I
A -25V

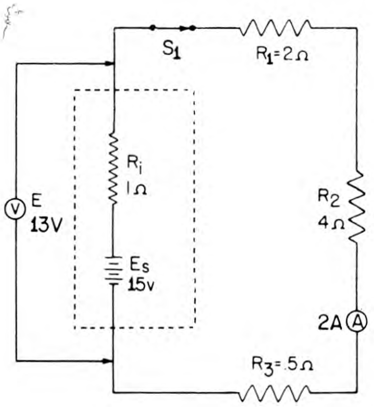
A REFERENCE POINT is a chosen point in a circuit to which all other points are compared.

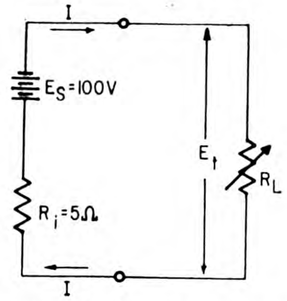
AN OPEN CIRCUIT is one in which a break exists in the complete conducting pathway.

A SHORT CIRCUIT is an accidental path of low resistance which passes an abnormally high amount of current.

INTERNAL RESISTANCE causes a drop in the terminal voltage of a source as current flows through the source. The decrease in terminal voltage is caused by the voltage drop across the internal resistance. All sources of electromotive force have some form of internal resistance.







ES= OPEN-CIRCUIT VOLTAGE OF SOURCE
Ri=INTERNAL RESISTANCE OF SOURCE
Et=TERMINAL VOLTAGE
RL=RESISTANCE OF LOAD
PL=POWER USED IN LOAD
I =CURRENT FROM SOURCE
% EFF = PERCENTAGE OF EFFICIENCY

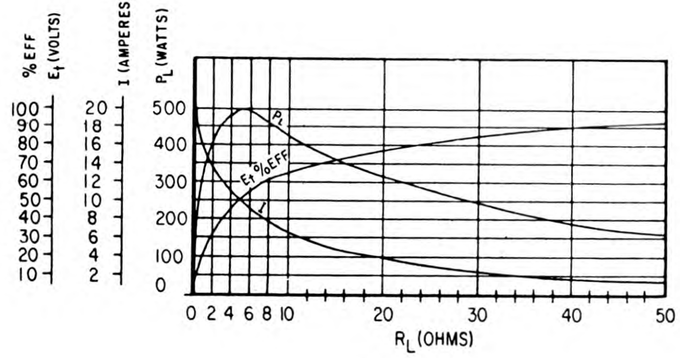
(A)
CIRCUIT AND SYMBOL DESIGNATIONS

R_L	E_t	I	P_L	% EFF.
0	0	20	0	0
1	16.7	16.7	278.9	16.7
2	28.6	14.3	409	28.6
3	37.5	12.5	468.8	37.5
4	44.4	11.1	492.8	44.4
5	50	10	500	50
6	54.5	9.1	496.0	54.5
7	58.3	8.3	483.9	58.3
8	61.6	7.7	474.3	61.6
9	64.3	7.1	456.5	64.3
10	66.7	6.7	446.9	66.7
20	80	4	320	80
30	85.7	2.9	248.5	85.7
40	88.9	2.2	195.6	88.9
50	90.9	1.9	172.7	90.9

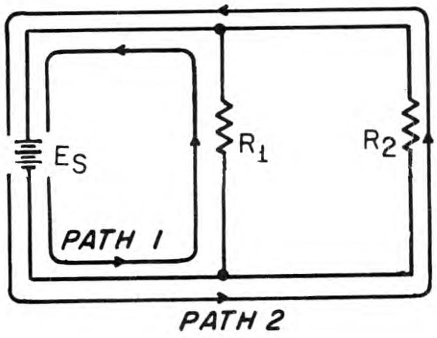
(B)
CHART

HIGH EFFICIENCY in a circuit is achieved when the resistance of the load is high with respect to the resistance of the source.

POWER TRANSFER in a circuit is highest when the resistance of the load equals the resistance of the source.



(C)
GRAPH

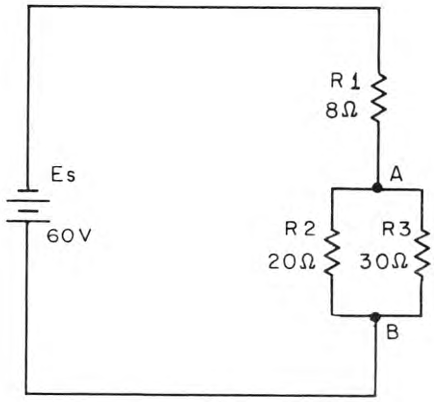


A PARALLEL CIRCUIT is a circuit having more than one current path connected to a common voltage source.

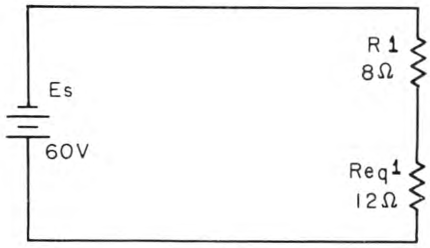
RULES FOR PARALLEL D.C. CIRCUITS:

- The same voltage exists across each branch of a parallel circuit and is equal to the source voltage.
- The current through a branch of a parallel network is inversely proportional to the amount of resistance of the branch.
- The total current of a parallel circuit is equal to the sum of the currents of the individual branches of the circuit.
- The total resistance of a parallel circuit is equal to the reciprocal of the sum of the reciprocals of the individual resistances of the circuit.
- The total power consumed in a parallel circuit is equal to the sum of the power consumptions of the individual resistances.

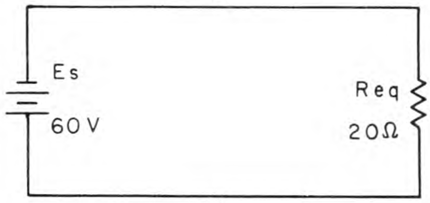
THE SOLUTION OF A COMBINATION CIRCUIT is a matter of applying the laws and rules for series and parallel circuits as applicable.



A



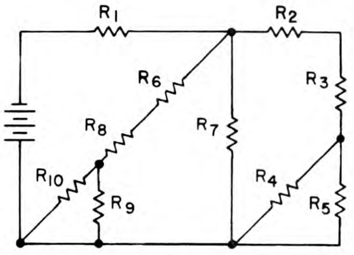
B



C

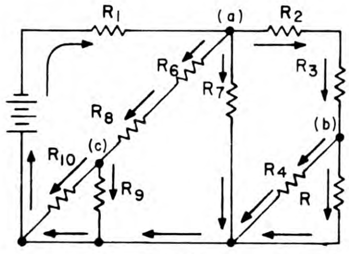
ALL PARALLEL CIRCUITS ARE COMBINATION CIRCUITS when the internal resistance of the source is taken into account.

REDRAWING CIRCUITS FOR CLARITY is accomplished in the following steps:

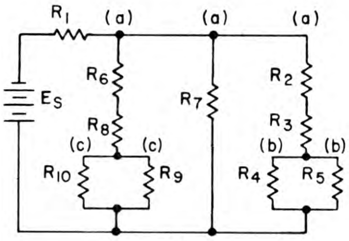

R1
R2
R6
R3
R8
R7
R10
R4
R9
R5

(A)

1. Trace the current paths in the circuit.
2. Label the junctions in the circuit.
3. Recognize points which are at the same potential.
4. Visualize rearrangements, "stretching" or "shrinking", of connecting wires.
5. Redraw the circuit into simpler form (through stages if necessary).

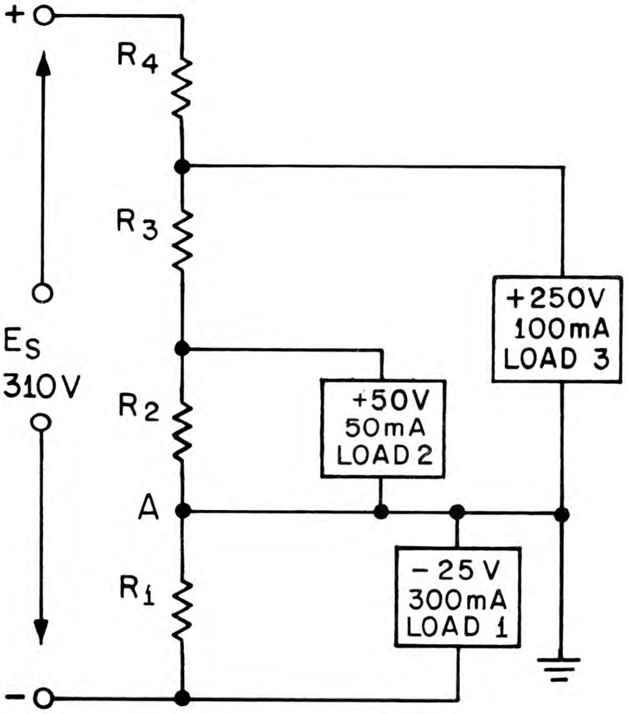

R1
(a)
R2
R6
R7
R3
R8
(b)
R10
(c)
R9
R4
R

(B)


R1
(a)
(a)
(a)
R6
R2
ES
R7
R3
R8
(c)
(c)
(b)
(b)
R10
R9
R4
R5

(C)

EQUIPMENT PROTECTION from short-circuit current is accompished by use of fuses and other circuit protection devices.


+
R4
R3
ES
310V
R2
A
R1
-
+250V
100mA
LOAD 3
+50V
50mA
LOAD 2
-25V
300mA
LOAD 1

A VOLTAGE DIVIDER is a series circuit in which desired portions of the source voltage may be tapped off for use in equipment. Both negative and positive voltage can be provided to the loads by the proper selection of the reference point (ground).

ELECTRICAL SAFETY PRECAUTIONS must be observed. A fatal shock can occur from 0.1 ampere of current. Voltages as low as 30 volts have been recorded as causing sufficient current to be fatal.

ALL LIVE ELECTRICAL CIRCUITS shall be treated as potential hazards at all times.

ELECTRONIC OR ELECTRICAL EQUIPMENT discovered to be faulty or unsafe should be reported immediately to proper authority.

ELECTRICAL OR ELECTRONIC EQUIPMENT should be used and repaired by authorized personnel only.

A CO_2 EXTINGUISHER should be used to extinguish electrical fires.

FIRST AID FOR ELECTRICAL SHOCK includes the following actions:

- Remove the victim from the source of the shock.

- Check the victim to see if the victim is breathing.

- If the victim is not breathing, give artifical ventilation. The preferred method is mouth-to-mouth.

- CPR may be necessary if the heartbeat has stopped, but do not attempt this unless you have been trained in its use. OBTAIN MEDICAL ASSISTANCE AS SOON AS POSSIBLE.

APPENDIX I

GLOSSARY

AMMETER.—An instrument for measuring the amount of electron flow in amperes.

AMPERE.—The basic unit of electrical current.

ANODE.—A positive electrode of an electrochemical device (such as a primary or secondary electric cell) toward which the negative ions are drawn.

ATTRACTION.—The force that tends to make two objects approach each other. Attraction exists between two unlike magnetic poles (North and South) or between two unlike static charges (plus and minus).

BATTERY.—A device for converting chemical energy into electrical energy.

BATTERY CAPACITY.—The amount of energy available from a battery. Battery capacity is expressed in ampere-hours.

BLEEDER CURRENT.—The current through a bleeder resistor. In a voltage divider, bleeder current is usually determined by the 10 percent rule of thumb.

BLEEDER RESISTOR.—A resistor which is used to draw a fixed current.

BRANCH.—An individual current path in a parallel circuit.

CATHODE.—The general name for any negative electrode.

CELL.—A single unit that transforms chemical energy into electrical energy. Batteries are made up of cells.

CHARGE.—Represents electrical energy. A material having an excess of electrons is said to have a negative charge. A material having a deficiency of electrons is said to have a positive charge.

CIRCUIT.—The complete path of an electric current.

CIRCULAR MIL.—An area equal to that of a circle with a diameter of 0.001 inch. It is used for measuring the cross-sectional area of wires.

COMBINATION CIRCUIT.—A series-parallel circuit.

CONDUCTANCE.—The ability of a material to conduct or carry an electric current. It is the reciprocal of the resistance of the material, and is expressed in mhos or siemans.

CONDUCTIVITY.—Ease with which a substance transmits electricity.

CONDUCTOR.—(1) A material with a large number of free electrons. (2) A material which easily permits electric current to flow.

COULOMB.—A measure of the quantity of electricity. One coulomb is equal to 6.28×10^{18} electrons.

COULOMB'S LAW.—Also called the law of electric charges or the law of electrostatic attraction. Coulomb's Law states that charged bodies attract or repel each other with a force that is directly proportional to the product of their individual charges and inversely proportional to the square of the distance between them.

CPR.–Cardio-Pulminary Resuscitation.

CROSS-SECTIONAL AREA.–The area of a "slice" of an object. When applied to electrical conductors it is usually expressed in circular mils.

CURRENT.—The flow of electrons past a reference point. The passage of electrons through a conductor. Measured in amperes.

DEAD SHORT.–A short circuit having minimum resistance.

DIELECTRIC FIELD.–The space between and around charged bodies in which their influence is felt. Also called Electric Field of Force or an Electrostatic Field.

DIRECT CURRENT.–An electric current that flows in one direction only.

DOMAIN THEORY.–A theory of magnetism based upon the electron-spin principle. Spinning electrons have a magnetic field. If more electrons spin in one direction than another, the atom is magnetized.

DRY CELL.–An electrical cell in which the electrolyte is not a liquid. In most dry cells the electrolyte is in the form of a paste.

EFFICIENCY.–The ratio of output power to input power, generally expressed as a percentage.

ELECTRIC CURRENT.–The flow of electrons.

ELECTRICAL CHARGE.–Symbol Q, q. Electric energy stored on or in an object. The negative charge is caused by an excess of electrons; the positive charge is caused by a deficiency of electrons.

ELECTROCHEMICAL.–The action of converting chemical energy into electrical energy.

ELECTRODE.–The terminal at which electricity passes from one medium into another, such as in an electrical cell where the current leaves or returns to the electrolyte.

ELECTROLYTE.–A solution of a substance which is capable of conducting electricity. An electrolyte may be in the form of either a liquid or a paste.

ELECTROMAGNET.–An electrically excited magnet capable of exerting mechanical force, or of performing mechanical work.

ELECTROMAGNETIC.–The term describing the relationship between electricity and magnetism. Having both magnetic and electric properties.

ELECTROMAGNETIC INDUCTION.–The production of a voltage in a coil due to a change in the number of magnetic lines of force (flux linkages) passing through the coil.

ELECTRON.–The elementary negative charge that revolves around the nucleus of an atom.

ELECTRON SHELL.–A group of electrons which have a common energy level that forms part of the outer structure (shell) of an atom.

ELECTROSTATIC.–Pertaining to electricity at rest, such as charges on an object (static electricity).

ELEMENT.–A substance, in chemistry, that cannot be divided into simpler substances by any means ordinarily available.

EMF.–(Electromotive Force) The force which causes electricity to flow between two points with different electrical charges or when there is a difference of potential between the two points. The unit of measurement in volts.

ENERGY.—The ability or capacity to do work.

EQUIVALENT RESISTANCE.—(R_{eq}) A resistance that represents the total ohmic values of a circuit component or group of circuit components. Usually drawn as a single resistor when simplifying complex circuits.

FERROMAGNETIC MATERIAL.—A highly magnetic material, such as iron, cobalt, nickel, or alloys, make up these materials.

FIELD OF FORCE.—A term used to describe the total force exerted by an action-at-a-distance phenomenon such as gravity upon matter, electric charges acting upon electric charges, magnetic forces acting upon other magnets or magnetic materials.

FIXED RESISTOR.—A resistor having a definite resistance value that cannot be adjusted.

FLUX.—In electrical or electromagnetic devices, a general term used to designate collectively all the electric or magnetic lines of force in a region.

FLUX DENSITY.—The number of magnetic lines of force passing through a given area.

GAS.—One of the three states of matter having no fixed form or volume. (Steam is a gas.)

GRAPH.—A pictorial presentation of the relation between two or more variable quantities, such as between an applied voltage and the current it produces in a circuit.

GROUND POTENTIAL.—Zero potential with respect to the ground or earth.

HORSEPOWER.—The English unit of power, equal to work done at the rate of 550 foot-pounds per second. Equal to 746 watts of electrical power.

HORSESHOE MAGNET.—A permanent magnet or electromagnet bent into the shape of a horseshoe or having a U-shape to bring the two poles near each other.

HYDROMETER.—An instrument used to measure specific gravity. In batteries hydrometers are used to indicate the state of charge by the specific gravity of the electrolyte.

INDUCED CHARGE.—An electrostatic charge produced on an object by the electric field that surrounds a nearby object.

INDUCED CURRENT.—Current due to the relative motion between a conductor and a magnetic field.

INDUCED ELECTROMOTIVE FORCE.—The electromotive force induced in a conductor due to the relative motion between a conductor and a magnetic field.

INDUCED VOLTAGE.—See Induced Electromotive Force.

INDUCTION.—The act or process of producing voltage by the relative motion of a magnetic field across a conductor.

INFINITE.—(1) Extending indefinitely, endless. (2) Boundless having no limits. (3) An incaluculable number.

INSULATION.—(1) A material used to prevent the leakage of electricity from a conductor and to provide mechanical spacing or support to protect against accidental contact. (2) Use of material in which current flow is negligible to surround or separate a conductor to prevent loss of current.

INSULATOR.—(1) Material of such low conductivity that the flow of current through it can usually be neglected. (2) Device having high-electric resistance, used for supporting or separating conductors so as to prevent undesired flow of current from the conductors to other objects.

INVERSELY.—Inverted or reversed in position or relationship.

ION.—An electrically charged atom or group of atoms. Negative ions have an excess of electrons; positive ions have a deficiency of electrons.

IONIZE.—To make an atom or molecule of an element lose an electron, as by X-ray bombardment, and thus be converted into a positive ion. The freed electron may attach itself to a neutral atom or molecule to form a negative ion.

JUNCTION.—(1) The connection between two or more conductors. (2) The contact between two dissimilar metals or materials, as is in a thermocouple.

KILO.—A prefix meaning one thousand.

KINETIC ENERGY.—Energy which a body possesses by virtue of its motion.

KIRCHHOFF'S LAWS.—(1) The algebraic sum of the currents flowing toward any point and the current flowing from that point in an electric network is zero. (2) The algebraic sum of the products of the current and resistance in each of the conductors in any closed path in a network is equal to the algebraic sum of the electromotive forces in the path.

LAW OF MAGNETISM.—Like poles repel; unlike poles attract.

LEAD-ACID CELL.—A cell in an ordinary storage battery, in which electrodes are grids of lead containing an active material consisting of certain lead oxides that change in composition during charging and discharging. The electrodes or plates are immersed in an electrolyte of diluted sulfuric acid.

LINE OF FORCE.—A line in an electric or magnetic field that shows the direction of the force.

LIQUID.—One of the three states of matter which has a definite volume but no definite form. (Water is a liquid.)

LOAD.—(1) A device through which an electric current flows and which changes electrical energy into another form. (2) Power consumed by a device or circuit in performing its function.

LOCAL ACTION.—A continuation of current flow within an electrical cell when there is no external load. Caused by impurities in the electrode.

MAGNETIC FIELD.—The space in which a magnetic force exists.

MAGNETIC POLES.—The section of a magnet where the flux lines are concentrated; also where they enter and leave the magnet.

MAGNETISM.—The property possessed by certain materials by which these materials can exert mechanical force on neighboring masses of magnetic materials; and can cause currents to be induced in conducting bodies moving relative to the magnetized bodies.

MATTER.—Any physical entity which possesses mass.

MEGA.—A prefix meaning one million, also Meg.

MHO.—Unit of conductance; the reciprocal of the ohm.

MICRO.—A prefix meaning one-millionth.

MILLI.—A prefix meaning one-thousandth.

NEGATIVE ELECTRODE.—A terminal or electrode having more electrons than normal. Electrons flow out of the negative terminal of a voltage source.

NEGATIVE TEMPERATURE COEFFICIENT.—The temperature coefficient expressing the amount of reduction in the value of a quantity, such as resistance for each degree of increase in temperature.

NETWORK.—A combination of electrical components. In a parallel circuit it is composed of two or more branches.

NEUTRAL.—In a normal condition, hence neither positive nor negative. A neutral object has a normal number of electrons.

OHM.—The unit of electrical resistance. It is that value of electrical resistance through which a constant potential difference of 1 volt across the resistance will maintain a current flow of 1 ampere through the resistance.

OHMIC VALUE.—Resistance in ohms.

OHM'S LAW.—The current in an electric circuit is directly proportional to the electromotive force in the circuit. The most common form of the law is $E = IR$, where E is the electromotive force or voltage across the circuit, I is the current flowing in the circuit, and R is the resistance of the circuit.

OPEN CIRCUIT.—(1) The condition of an electrical circuit caused by the breaking of continuity of one or more conductors of the circuit; usually an undesired condition. (2) A circuit which does not provide a complete path for the flow of current.

PARALLEL CIRCUIT.—Two or more electrical devices connected to the same pair of terminals so separate currents flow through each; electrons have more than one path to travel from the negative to the positive terminal.

PERMEABILITY.—The measure of the ability of a material to act as a path for magnetic lines of force.

PHOTOELECTRIC VOLTAGE.—A voltage produced by light.

PICO.—A prefix adopted by the National Bureau of Standards meaning 10^{-12}.

PIEZOELECTRIC EFFECT.—The effect of producing a voltage by placing a stress, either by compression, expansion, or twisting, on a crystal and, conversely, producing a stress in a crystal by applying a voltage to it.

PLATE.—One of the electrodes in a storage battery.

POLARITY.—(1) The condition in an electrical circuit by which the direction of the flow of current can be determined. Usually applied to batteries and other direct voltage sources. (2) Two opposite charges, one positive and one negative. (3) A quality of having two opposite magnetic poles, one north and the other south.

POLARIZATION.—The effect of hydrogen surrounding the anode of a cell which increases the internal resistance of the cell.

POTENTIAL ENERGY.—Energy due to the position of one body with respect to another body or to the relative parts of the same body.

POTENTIOMETER.—A 3-terminal resistor with one or more sliding contacts, which functions as an adjustable voltage divider.

POWER.—The rate of doing work or the rate of expending energy. The unit of electrical power is the watt.

PRIMARY CELL.—An electrochemical cell in which the chemical action eats away one of the electrodes, usually the negative electrode.

RECIPROCAL.—The value obtained by dividing the number 1 by any quantity.

REFERENCE POINT.—A point in a circuit to which all other points in the circuit are compared.

RELUCTANCE.—A measure of the opposition that a material offers to magnetic lines of force.

REPULSION.—The mechanical force tending to separate bodies having like electrical charges or like magnetic polarity.

RESIDUAL MAGNETISM.—Magnetism remaining in a substance after removal of the magnetizing force.

RESISTANCE.—(1) The property of a conductor which determines the amount of current that will flow as the result of the application of a given electromotive force. All conductors possess some resistance, but when a device is made especially for the purpose of limiting current flow, it is called a resistor. A resistance of 1 ohm will allow a current of 1 ampere to flow through it when a potential of 1 volt is applied. (2) The opposition which a device or material offers to the flow of current. The effect of resistance is to raise the temperature of the material or device carrying the current. (3) A circuit element designed to offer a predetermined resistance to current flow.

RESISTOR.—The electrical component which offers resistance to the flow of current. It may be a coil of fine wire or a composition rod.

RETENTIVITY.—The ability of a material to retain its magnetism.

RHEOSTAT.—(1) A resistor whose value can be varied. (2) A variable resistor which is used for the purpose of adjusting the current in a circuit.

SCHEMATIC CIRCUIT DIAGRAM.—A circuit diagram in which component parts are represented by simple, easily drawn symbols. May be called schematic.

SCHEMATIC SYMBOLS.—A letter, abbreviation, or design used to represent specific characteristics or components on a schematic diagram.

SECONDARY CELL.—A cell that can be recharged by passing a current through the cell in a direction opposite to the discharge current.

SERIES CIRCUIT.—An arrangement where electrical devices are connected so that the total current must flow through all the devices; electrons have one path to travel from the negative terminal to the positive terminal.

SERIES-PARALLEL CIRCUIT.—A circuit that consists of both series and parallel networks.

SHELF LIFE.—The period of time that a cell or battery may be stored and still be useful.

SHIELDING.—A metallic covering used to prevent magnetic or electromagnetic fields from effecting an object.

SHORT CIRCUIT.—A low resistance connection between two points of different potential in a circuit, usually accidental and usually resulting in excessive current flow that may cause damage.

SIEMANS.—The new and preferred term for mho.

SOLID.—One of the three states of matter which has definite volume and shape. (Ice is a solid.)

SOURCE VOLTAGE.—The device which furnishes the electrical energy used by a load.

SPECIFIC GRAVITY.—The ratio between the density of a substance and that of pure water at a given temperature.

STATIC ELECTRICITY.—Stationary electricity that is in the form of a charge. The accumulated electric charge on an object.

SWITCH.—A device to connect, disconnect, or change the connections in an electrical circuit.

TAPPED RESISTOR.—A wire-wound, fixed resistor having one or more additional terminals along its length, generally for voltage-divider applications.

TEMPERATURE COEFFICIENT.—The amount of change of resistance in a material per unit change in temperature.

TERMINAL.—An electrical connection.

THERMOCOUPLE.—A junction of two dissimilar metals that produces a voltage when heated.

TOLERANCE.—(1) The maximum error or variation from the standard permissible in a measuring instrument. (2) A maximum electrical or mechanical variation from specifications which can be tolerated without impairing the operation of a device.

TOTAL RESISTANCE.—(R_T) The equivalent resistance of an entire circuit. For a series circuit: $R_T = R_1 + R_2 + R_3 \ldots R_n$ For parallel circuits: $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \frac{1}{R_n}$

UNIDIRECTIONAL.—In one direction only.

VALENCE.—The measure of the extent to which an atom is able to combine directly with other atoms. It is believed to depend on the number and arrangement of the electrons in the outermost shell of the atom.

VALENCE SHELL.—The electrons that form the outermost shell of an atom.

VARIABLE RESISTOR.—A wire-wound or composition resistor, the value of which may be changed.

VOLT.—The unit of electromotive force or electrical pressure. One volt is the pressure required to send 1 ampere of current through a resistance of 1 ohm.

VOLTAGE.—(1) The term used to signify electrical pressure. Voltage is a force which causes current to flow through an electrical conductor. (2) The voltage of a circuit is the greatest effective difference of potential between any two conductors of the circuit.

VOLTAGE DIVIDER.—A series circuit in which desired portions of the source voltage may be tapped off for use in equipment.

VOLTAGE DROP.—The difference in voltage between two points. It is the result of the loss of electrical pressure as a current flows through a resistance.

WATT.—The practical unit of electrical power. It is the amount of power used when one ampere of d.c. flows through a resistance of one ohm.

WATTAGE RATING.—A rating expressing the maximum power that a device can safely handle.

WATT-HOUR.—A practical unit of electrical energy equal to one watt of power for one hour.

WEBER'S THEORY.—A theory of magnetism which assumes that all magnetic material is composed of many tiny magnets. A piece of magnetic material that is magnetized has all of the tiny magnets aligned so that the north pole of each magnet points in one direction.

WIRE.—A solid or stranded group of solid, cylindrical conductors having low resistance to current flow, with any associated insulation.

WORK.—The product of force and motion.

APPENDIX II

LAWS OF EXPONENTS

The International Symbols Committee has adopted prefixes for denoting decimal multiples of units. The National Bureau of Standards has followed the recommendations of this committee, and has adopted the following list of prefixes:

Numbers	Powers of ten	Prefixes	Symbols
1, 000, 000, 000, 000	10^{12}	tera	T
1, 000, 000, 000	10^9	giga	G*
1, 000, 000	10^6	mega	M*
1, 000	10^3	kilo	k *
100	10^2	hecto	h
10	10	deka	da
. 1	10^{-1}	deci	d
. 01	10^{-2}	centi	c
. 001	10^{-3}	milli	m*
. 000001	10^{-6}	micro	u *
. 000000001	10^{-9}	nano	n
. 000000000001	10^{-12}	pico	p *
. 000000000000001	10^{-15}	femto	f
. 000000000000000001	10^{-18}	atto	a

To multiply like (with same base) exponential quantities, add the exponents. In the language of alegebra the rule is $a^m \times a^n = a^{m+n}$

$$10^4 \times 10^2 = 10^{4+2} = 10^6$$

$$0.003 \times 825.2 = 3 \times 10^{-3} \times 8.252 \times 10^2$$

$$= 24.756 \times 10^{-1} = 2.4756$$

To divide exponential quantities, subtract the exponents. In the language of algebra the rule is

$$\frac{a^m}{a^n} = a^{m-n} \text{ or}$$

$$10^8 \div 10^2 = 10^6$$

$$3,000 \div 0.015 = (3 \times 10^3) \div (1.5 \times 10^{-2})$$

$$= 2 \times 10^5 = 200,000$$

To raise an exponential quantity to a power, multiply the exponents. In the language of algebra $(x^m)^n = x^{mn}$.

$$(10^3)^4 = 10^{3\times 4} = 10^{12}$$

$$2,500^2 = (2.5 \times 10^3)^2 = 6.25 \times 10^6 = 6,250,000$$

Any number (except zero) raised to the zero power is one. In the language of algebra $x^0=1$

$$x^3 \div x^3 = 1$$

$$10^4 \div 10^4 = 1$$

Any base with a negative exponent is equal to 1 divided by the base with an equal positive exponent. In the language of algebra $x^{-a} = \frac{1}{x^a}$

$$10^{-2} = \frac{1}{10^2} = \frac{1}{100}$$

$$5a^{-3} = \frac{5}{a^3}$$

$$(6a)^{-1} = \frac{1}{6a}$$

To raise a product to a power, raise each factor of the product to that power.

$$(2 \times 10)^2 = 2^2 \times 10^2$$

$$3,000^3 = (3 \times 10^3)^3 = 27 \times 10^9$$

To find the nth root of an exponential quantity, divide the exponent by the index of the root. Thus, the nth root of $a^m = a^{m/n}$.

$$\sqrt{x^6} = x^{6/2} = x^3$$

$$\sqrt[3]{64 \times 10^3} = 4 \times 10 = 40$$

---

*Generally used with electrical quantities.

APPENDIX III

SQUARE AND SQUARE ROOTS

N	N^2	$\sqrt{N}$	N	N^2	$\sqrt{N}$	N	N^2	$\sqrt{N}$
1	1	1.000	41	1681	6.4031	81	6561	9.0000
2	4	1.414	42	1764	6.4807	82	6724	9.0554
3	9	1.732	43	1849	6.5574	83	6889	9.1104
4	16	2.000	44	1936	6.6332	84	7056	9.1652
5	25	2.236	45	2025	6.7082	85	7225	9.2195
6	36	2.449	46	2116	6.7823	86	7396	9.2736
7	49	2.646	47	2209	6.8557	87	7569	9.3274
8	64	2.828	48	2304	6.9282	88	7744	9.3808
9	81	3.000	49	2401	7.0000	89	7921	9.4340
10	100	3.162	50	2500	7.0711	90	8100	9.4868
11	121	3.3166	51	2601	7.1414	91	8281	9.5394
12	144	3.4641	52	2704	7.2111	92	8464	9.5917
13	169	3.6056	53	2809	7.2801	93	8649	9.6437
14	196	3.7417	54	2916	7.3485	94	8836	9.6954
15	225	3.8730	55	3025	7.4162	95	9025	9.7468
16	256	4.0000	56	3136	7.4833	96	9216	9.7980
17	289	4.1231	57	3249	7.5498	97	9409	9.8489
18	324	4.2426	58	3364	7.6158	98	9604	9.8995
19	361	4.3589	59	3481	7.6811	99	9801	9.9499
20	400	4.4721	60	3600	7.7460	100	10000	10.0000
21	441	4.5826	61	3721	7.8102	101	10201	10.0499
22	484	4.6904	62	3844	7.8740	102	10404	10.0995
23	529	4.7958	63	3969	7.9373	103	10609	10.1489
24	576	4.8990	64	4096	8.0000	104	10816	10.1980
25	625	5.0000	65	4225	8.0623	105	11025	10.2470
26	676	5.0990	66	4356	8.1240	106	11236	10.2956
27	729	5.1962	67	4489	8.1854	107	11449	10.3441
28	784	5.2915	68	4624	8.2462	108	11664	10.3923
29	841	5.3852	69	4761	8.3066	109	11881	10.4403
30	900	5.4772	70	4900	8.3666	110	12100	10.4881
31	961	5.5678	71	5041	8.4261	111	12321	10.5357
32	1024	5.6569	72	5184	8.4853	112	12544	10.5830
33	1089	5.7447	73	5329	8.5440	113	12769	10.6301
34	1156	5.8310	74	5476	8.6023	114	12996	10.6771
35	1225	5.9161	75	5625	8.6603	115	13225	10.7238
36	1296	6.0000	76	5776	8.7178	116	13456	10.7703
37	1369	6.0828	77	5929	8.7750	117	13689	10.8167
38	1444	6.1644	78	6084	8.8318	118	13924	10.8628
39	1521	6.2450	79	6241	8.8882	119	14161	10.9087
40	1600	6.3246	80	6400	8.9443	120	14400	10.9545

For numbers up to 120. For larger numbers divide into factors smaller than 120.

Examples: $\sqrt{225}$ and $\sqrt{16200}$

$225 = 5 \times 45$
$\sqrt{225} = \sqrt{5} \times \sqrt{45}$
$\sqrt{225} = 2.236 \times 6.7082$
$\sqrt{225} = 15$

$16200 = 100 \times 81 \times 2$
$\sqrt{16200} = \sqrt{100} \times \sqrt{81} \times \sqrt{2}$
$\sqrt{16200} = 10 \times 9 \times 1.414$
$\sqrt{16200} = 127.26$

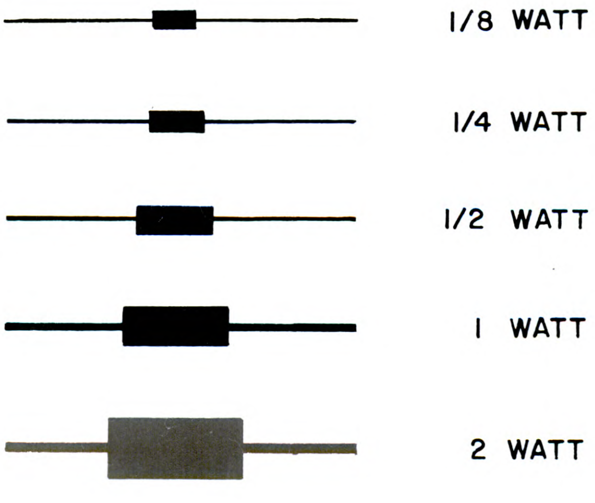
APPENDIX IV

COMPARISON OF UNITS IN ELECTRIC AND MAGNETIC CIRCUITS; AND CARBON RESISTOR SIZE COMPARISON BY WATTAGE RATING

Comparison of Units in Electric and Magnetic Circuits

	Electric circuit	Magnetic circuit
Force.	Volt, E, or e. m. f.	Gilberts, F, or m. m. f.
Flow	Ampere, I	Flux, Φ , in maxwells
Opposition.	Ohms, R	Reluctance, $\mathcal{R}$
Law.	Ohm's law, $I = \frac{E}{R}$	Rowland's law, $\Phi = \frac{F}{\mathcal{R}}$
Intensity of force	Volts per cm. of length.	$H = \frac{1.257IN}{L}$, gilberts per centimeter of length.
Density.	Current density—for example, amperes per cm^2.	Flux density—for example, lines per $cm.^2$, or gausses.

Carbon Resistor Size Comparison by Wattage Rating



APPENDIX V

USEFUL FORMULAS FOR D.C. CIRCUITS

Ohm's Law for D.C. Circuits

$$I = \frac{E}{R} = \frac{P}{E} = \sqrt{\frac{P}{R}}$$

$$R = \frac{E}{I} = \frac{P}{I^2} = \frac{E^2}{P}$$

$$E = IR = \frac{P}{I} = \sqrt{PR}$$

$$P = EI = \frac{E^2}{R} = I^2 R$$

Resistors in Series

$$R_T = R_1 + R_2 + \ldots R_n$$

Resistors in Parallel

Two resistors

$$R_T = \frac{R_1 R_2}{R_1 + R_2}$$

More than two

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \frac{1}{R_n}$$

Where R = resistance in ohms,
I = current in amperes,
E = potential across R in volts,
P = power in watts

OHM'S LAW FORMULAS FOR D.C. CIRCUITS

Known	Formulas for Determining Unknown Values of . . .			
Values	R	I	E	P
I&R			IR	$I^2 R$
I&E	$\frac{E}{I}$			EI
I&P	$\frac{P}{I^2}$		$\frac{P}{I}$	
R&E		$\frac{E}{R}$		$\frac{E^2}{R}$
R&P		$\sqrt{\frac{P}{R}}$	$\sqrt{PR}$	
E&P	$\frac{E^2}{P}$	$\frac{P}{E}$		

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